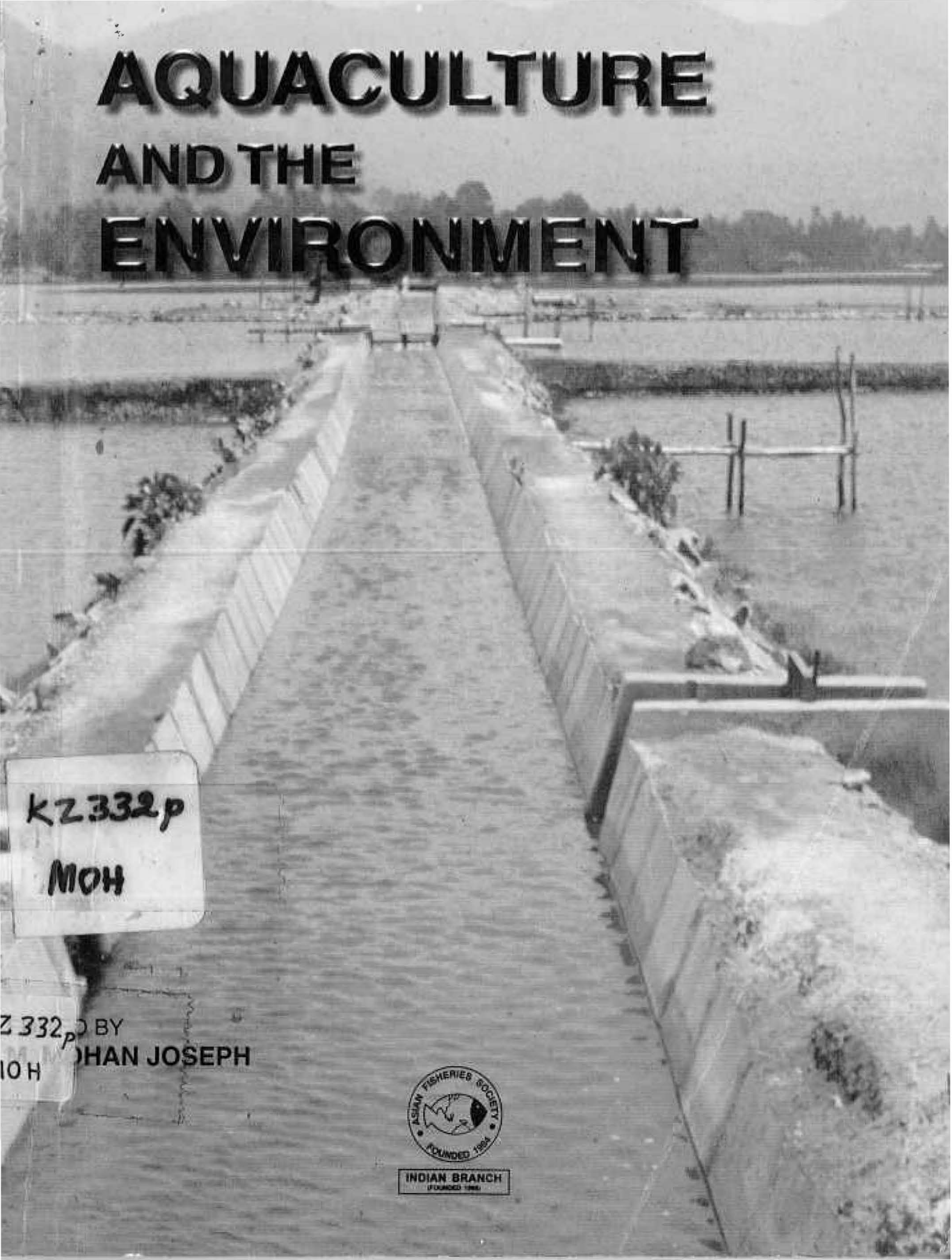
AQUACULTURE AND THE ENVIRONMENT



D BY
M. M HAN JOSEPH

ASIAN FISHERIES SOCIETY
FOUNDED 1984

INDIAN BRANCH

Aquaculture and the Environment

Edited by

M. Mohan Joseph

1999

Asian Fisheries Society, Indian Branch

Aquaculture and the Environment

Edited by
M. Mohan Joseph

(Proceedings of the International Symposium "Environment - Aquaculture Interaction", 27 November, 1996, Fourth Indian Fisheries Forum, 24-28 November, 1996, Kochi. Asian Fisheries Society, Indian Branch)

1999
Printed in India

Published by
Asian Fisheries Society, Indian Branch
College of Fisheries Campus
University of Agricultural Sciences
Mangalore 575 002
India

ISBN 81-85340-17 - X

Contents

Preface

This special publication of the Asian Fisheries Society, Indian Branch (AFSIB) is a result of an international symposium "Environment - Aquaculture Interaction" held on 27 November, 1996 during the course of the Fourth Indian Fisheries Forum organized by the AFSIB from 24 to 28 November, 1996 in Kochi, Kerala State, India. This symposium served as a forum for updating and interacting for all those involved in research, monitoring, legislative development and the regulatory aspects of aquaculture activity and environmental quality. Five invited papers were presented, of which four have been edited and published in this volume.

In recent years, the Asian region has been witnessing significant developments in aquaculture which has assumed the status of an industry. Such developments have also attracted growing concerns on the environmental, economic and social impacts of aquaculture and these issues have generated interest among a wide section of the society. Concerns and actions of both aquaculturists and environmentalists have become debatable issues. A great deal of information and misinformation are presently available on the benefits and costs of aquaculture development vis-a-vis environmental quality. In this scene, an unemotional analysis examining the issues from all angles is the need of the hour and the present volume hopefully meets this requirement.

There are four contributions presented in this volume. Hassanai Kongkeo examines the environmental concerns related to shrimp farming, finfish culture and mollusc culture in his presentation "Coastal Aquaculture and the Environment". He overviews the impacts on mangroves and suggests appropriate measures needed for safe culture practices, improved environment quality and reduced coastal pollution. The author clarifies that 'intensive shrimp culture system may be the only solution to prevent mangroves from being destroyed through extensive farming'. Environmental management measures in NACA (Network of Aquaculture Centres in Asia-Pacific) countries are also reviewed in this paper.

Environmental issues in Indian freshwater aquaculture have been examined by S. Ayyappan and J.K. Jena. Topics ranging from bio-diversity to marketing and hygiene are covered in this paper. Environmental quality in the context of supplementary feeding practices, integrated fish farming and water budgeting has been examined in the Indian situation. Depuration of fish cultured in waste waters and the public safety aspects have been highlighted in this paper. M. Devaraj and co-authors describe various packages of practices for sustainable and eco-friendly land-based saline aquaculture and seafarming. Guidelines for safe and environment friendly farming of marine organisms ranging from shrimp to mussels, oysters, clams, pearls, crabs, seaweeds and finfish are presented along with details of farming techniques, husbandry, health management and economics. Application of genetics to aquaculture in the light of recent developments resulting from the pioneering work carried out at ICLARM has been discussed by Meryl J. Williams in her presentation. Recent research results have opened up wider possibilities in the application of genetic engineering in aquaculture and the author has painted a broad picture of the scenario in her presentation. ICLARM's pioneering work on genetic application in aquaculture carried out in various countries has been highlighted. An insight into the GIFT project and GIFT technology has been provided.

The four papers presented in this volume portray four distinctly different phases of recent aquaculture developments in the Asian region. Lessons from the experiences of active researchers will certainly provide the required insights presently needed to understand and practise safe, sustainable, eco-friendly and responsible aquaculture. The present efforts through this volume are a small step towards achieving this goal in the Asian region so that aquaculture regains its respectable status it rightly deserves in the food security of the Asian region.

M. Mohan Joseph.

1

Coastal Aquaculture and the Environment

HASSANAI KONGKEO

Network of Aquaculture Centres in Asia - Pacific
Department of Fisheries Compound
Kasetsart University Campus
Ladyao, Jatujak, Bangkok 10900, Thailand

1. Introduction

Aquaculture production has been increasing worldwide while culture practices have undergone considerable intensification and diversification. Although there have been substantial socio-economic benefits including increased nutrition level, income, employment and foreign exchange, aquaculture also utilizes resources and causes environmental changes. In fact, the majority of aquaculture practices, particularly inland aquaculture, have had little effect on the ecosystems. Some cases of environmental degradation in coastal areas have occurred due to, for example, intensive cage culture operations in Europe and shrimp farming practices in southeast Asia and Latin America. In some cases, environmental problems have resulted from conversion of wetland habitats, nutrient and organic waste discharges, introduction of exotic species, chemical usages as well as from deterioration of water quality and decreasing availability of suitable sites for aquaculture (Barg, 1992).

Coastal aquaculture is dominated by shrimp culture while smaller quantities of molluscs, fish and seaweeds are also produced through aquaculture. In recent years, intensive shrimp culture has been beset by environment-related disease and water quality problems, which have caused significant

AQUACULTURE AND THE ENVIRONMENT
ISBN 81-85340-17-X

economic losses to farmers and resulted in large-scale abandonment of ponds. The environment-related disease problems that hit the industry in late 1990's were widely thought to be a result of (1) a general deterioration in the quality of coastal water used for culture shrimp due to increasing pollutant loads from agriculture, industry and domestic sources; (2) self pollution by shrimp farmers through bad management practices; and (3) shrimp farms abstracting water already polluted by other shrimp farms (This problem is caused by high densities of farms which result in localized deterioration in water quality and easy transfer of pathogens). The case study of coastal aquaculture and environment was carried out in Thailand because aquaculture, particularly shrimp farming has been developed in very intensive ways so that it will very harmful to coastal environment. The solutions for environmental problems are also useful to the other countries in region which are going to intensify the shrimp culture system.

Coastal aquaculture in Thailand produces shrimp *(Penaeus mondon, P. merguiensis)*, oyster *(Crassostrea lugubris, C. belcheri)*, mussel *(Perna viridis, Modiola senhausenii)*, cockles *(Anadara granosa)*, crabs *(Scylla serrata)* and finfish *(Lates calcarifer, Epinephelus spp)*. In 1995, the yield of coastal aquaculture was 352,000 tonnes worth US$ 2,158 million to the Thai economy. Of the total production, 79.5% (280,000 tonnes) was from shrimp culture 19.4% (68,000 tonnes) was from shelfish and 1.1% (3,700 tonnes) was from finfish culture. The main spur for the development of coastal aquaculture in Thailand has been the high economic returns from the organisms cultured, which are mainly used for export. Development has been made possible by improvement in seed production techniques, culture technologies and infrastructure and Government incentives.

2. Environmental Concerns Related to Coastal Shrimp Culture

There are a number of environmental issues linked to the development of intensive shrimp culture in southeast Asia. The potential impacts of intensive shrimp culture on the environment are summarised in (Table 2) and are mainly linked to land, water and biological resources (FAO/NACA, 1995).

In Thailand, the most serious impacts are those associated with water resources, water pollution from pond effluent and siltation. Salinization of freshwater resources has now become less problematic as most shrimp farmers have reduced pond leakage by construction of separate drainage system, erection of strong dikes and preparation of well compacted pond bottom.

In addition, the shrimp culture industry is vulnerable to impacts from flood and storm, which cause physical damage to farms resulting in serious economic loss. In 1995, a number of farms in Thailand were seriously affected by floods. Other physical impacts are from sedimentation, siltation and erosion of coastal areas, which can lead to silting of supply canals and ponds. The

Table 1 : Production of shrimp in Thailand in 1994 (DOF,1995)

	Central	East	South-west	South-east	Total
Extensive (tonnes)	2,263	421	159	1,745	4,588
Semi-intensive (tonnes)	1,379	0	0	2,194	3,573
Intensive (tonnes)	10,793	106,738	43,217	94,533	255,281
Total (tonnes)	14,435	107,159	43,376	98,472	263,442
Area (ha)	24,196	20,727	5,267	22,031	72,221
Tonnes/ha/yr	0.60	5.19	8.25	4.44	3.63
Value (US$ million)	103.6	769.0	311.2	706.6	1,890.4
No. of farms	4,066	5,509	2,946	9,145	21,666

Table 2 : Environmental issues associated with intensive shrimp culture

Resource	Impact	Consequence
Land resources (construction)	Alteration of sedimentation and siltation patterns	May lead to the blocking of canals and farm water supplies.
	Alternation of estuarine habitats and circulation patterns	May lead to changes in habitats, salinity patterns and benthic populations.
	Conflicts with other users through removal of mangrove and loss of access	May result in loss of livelihood for coastal communities through loss of resource or access to traditional fishing or gathering grounds
Water resources	Salinisation of freshwater resources and agricultural land	Leads to social conflicts and restrictions of alternate uses of water and land resources
	Water pollution from pond effluent	Contributes to eutrophication of coastal waters
	Self pollution problems	Where many farms discharge into water supply canals a deterioration in water quality may occur and pathogens can transfer between farms more easily
	Chemical and drug use	Discharge to the environment with largely unknown environmental consequences
Biological resources	Removal of coastal mangrove forests for shrimp culture	Coastal erosion, saltwater intrusion, water quality deterioration and loss of biodiversity
	Shrimp seed resources	Decline in shrimp stocks

deterioration of coastal water quality is another constraint to coastal shrimp culture, which has been adversely affected by red tides resulting from eutrophication of coastal waters in some areas. High levels of organic pollution in water supplies from industrial, agricultural and domestic sources, leads to microbial contamination, thus increasing the chances of disease outbreak. Heavy metal and pesticide contamination of water has also been responsible for shrimp losses in some Asian countries.

3. Environmental Issues Associated with Finfish Culture

The most important environmental concerns associated with intensive marine finfish culture are related to water quality (Table 3). Intensive cage culture can have an adverse impact on water quality through the release of solid and soluble wastes (mainly uneaten feed and fish excreta). Soluble wastes are made up of matrials leached from the solid wastes as they fall through the water (such as nutrients and other organic matter) and fish metabolites (such as ammonia and urea). Solid wastes are made up primarily of uneaten feed and fish faeces which have relatively high organic contents and rich nutrients. If there is inadequate flushing or dilution of the cage wastes, these may accumulate beneath or around the cages leading to depleted dissolved oxygen and elevated nutrient levels which are toxic or stressful to aquatic life (e.g. unionized ammonia and nitrite).

In addition, intensive cage culture systems are very vulnerable to impacts from the environment particularly adverse weather conditions (such as floods or storms) and siltation caused by land erosion, deforestation, domestic and industrial waste discharges and land reclamation. Good water quality is esssential for successful cage culture while fish farms are vulnerable topoor quality water polluted with domestic or industrial wastes and oil. Harmful algal blooms or red tide have also caused significant economic losses to cage farms in Asia.

4. Environmental Issues Associated with Mollusc Culture

Compared with intensive finfish culture, environmental concerns associated with mollusc culture are low and normally occur where culture sites cover large area, have very high stocking

Table 3 : Potential environmental impacts of intentive marine cage culture (FAO/NACA, 1995)

Resources	Impact	Consequence
Water	Obstruction of navigation and conflicts over access to fishing grounds	Social conflicts
	Discharge of uneaten feed, fish faeces and excreta	Hypernutrification leading to localised dissolved oxygen depletion
		Localised accumulations of solid wastes
	Chemical and drug use	Released to the environment with unknown consequences
Biological	Use of wild juvenile fish	Decline in wild stocks leading to reduced natural productivity and loss of biodiversity

densities or are not properly managed. Mollusc culture can result in a positive and useful impact on the environment by assimilating particulate organic matter and reducung coastal eutrophication. Mollusc culture is, however, particularly sensitive to environmental pollution, particularly siltation and sedimentation, coastal eutrophication (which can result in decreased spat-fall from natural populations), harmful algal blooms (which can either be directly toxic to mollusc or make them unsuitable for consumption) and organic or industrial contamination (which can make the product unsuitable for human consumption).

5. Mangrove

Generally, the reduction in mangrove areas is mainly caused by mining, salt ponds, aquaculture and other agriculture activities, reclamation of sites for industries, urbanization, harbours and road construction which blocks tidal feed to mangrove. There were 312,732 ha of mangrove in 1975 (ten years before intensive shrimp farming took off as an industry in Thailand) which dwindled to 168,682 ha by 1993. During this 18-year period, about 65,000 ha or one-fifth of the 1975 cover was used for aquaculture. Less than 60% of this aquaculture area in mangrove zone was established in previously cleared or un-productive mangrove tracts while only 27,412 ha or 8.7% of the 1975 hectarage was cleared specifically for aquaculture (Aquaculture Asia, 1996). In addition, most of these areas are utilized for extensive and semi-intensive culture which produce only 3% of total cultured shrimp in the country. Therefore intensive shrimp culture should not be blamed for the destruction of mangrove.

Intensive shrimp culture operations have been utilizing land away from the unsuitable low lying mangrove areas. It is better practised in the non-acid and non-peaty soil of rice paddies. Coupled with technologies such as formulated feed, water quality management, efficient water pumps, disease control and hatchery protocols, shrimp culture has become more efficient, producing more shrimp from less culture area. Though the land costs for supra-tidal areas of rice fields are higher, the costs of construction are much lower

Table 4 : Environmental impacts of mollusc culture (FAO/NACA, 1995)

Resource	Impact	Consequence
Land	Large areas may interfere with direction and velocity of tidal current	Changes in sedimentation patterns
	May interfere with navigation	
Water	Accumulation of solid waste beneath culture sites	Localised deterioration in environmental quality
	Uptake of primary and secondary production	Can have positive impact on coastal eutrophication
Biological	Collection of wild seed	Impacts on wild stocks unknown

because heavy machines can be used effeciently. These legal supra-tidal lands can be used easily as collateral for bank loans for initital investment and operation. When shrimp are cultured in mangrove areas where water and soil contain high organic loads, disease problems always occur. Ponds developed in supra-tidal areas can be properly treated by completely drying out, without interference from seepage from supply canals, or by efficient removal of the fouled bottom layer by heavy machines. In order to prevent conflicts with rice farmers, the ponds must be designed to have proper drainage system without interfering with freshwater canals and the pond embankments should be well compacted to prevent seepage of saline water into rice paddies.

Farmers gradually have come to realize that intensive shrimp culture systems are sustainable while mangroves are not. While shrimp farming was admittedly a factor in destroying mangroves, the distinction must be made that this destruction was carried out in the name of unsophisticated extensive culture system. If extensive shrimp culture, which has low efficiency and is unsustainable, has to be expanded by bringing in more areas in the developing countries under culture, then the world's mangroves are seriously endangered. Therefore, the intensive shrimp culture system may be the only solution to prevent mangroves from being destroyed through extensive farming. In Thailand's case, 85% of the shrimp farms practise intensive culture system, utilizing relatively little land with great efficiency. This efficiency has benefited the mangrove ecosystem of Thailand in eliminating the need for mangrove clearing for shrimp farming. Intensive shrimp culture technology needs to be promoted through education and by discouraging newcomer shrimp farmers from utilizing the mangroves. Such technology should be disseminated globally for the purpose of conserving the remaining mangrove ecosystems around the world (Menasveta, 1996).

6. Shrimp Farm Effluent

The principal components of effluent from intensive shrimp culture include nutrients, shrimp faeces, dead plankton, small quantities of chemical and therapeutants as well as silt. Pond and effluent water quality tends to deteriorate through the grow-out period, as feeding rates increase with shrimp size and biomass. High quantities of poor quality effluents (in terms of nutrient loadings, total ammonia and unionised ammonia) are found during harvesting time, when shrimp biomass is at its maximum and pond water completely drained. On an average, water discharged during harvest contributes to 60% of the total volume of water discharged from shrimp culture and 70-80% of the total shrimp effluent loadings. In addition, a large quantity of accumulated sediment remains at the pond bottom after the pond is harvested and water drained out. Removing the sediment is regarded as essential by most shrimp farmers because allowing sediments to accumulate will adversely affect the water quality, benthic fauna, shrimp health and survival of shrimp in the next crop. In general, there are many ways of removing this sediment; e.g. by drying the pond and mechanical removal; by sucking in to reserved areas and by heavy flushing.

Although the farm effluents during culture contain elevated levels of BOD, nutrients and suspended solids compared with normal sea water, once discharged to the aquatic environment where they receive some dilution, it is unlikely that significant environmental impacts could occur if good dilution or flushing is available and the area is not overcrowded with too many farms. In addition, most shrimp farms discharge water very rarely during the culture period. So the quantities of effluent released are not large. Effluents released during harvest, however, is of much poorer quality and the impact of the harvest effluent will depend on the sensitivity of the receiving environment and the dilution which may be possible. In practice, farmers in each area avoid harvesting their shrimp at the same time so that the shrimp prices do not drop due to over- supply. Therefore it is improbable that the waste from harvest will

Table 5 : Shrimp farm effluent during operation compared with other types of wastewater

Parameter (mg/l)	Shrimp farm effluent	Harvest effluent	Domestic wastewater Untreated	Primary	Biological	Fish processing plant
BOD	4.0-10.2	–	300	200	30	10,000-18,000
Total nitrogen	0.03-1.24	5.25-14.8	75	60	40	700-4,530
Total phosphorus	0.001-2.02	0.08-0.8	20	15	12	120-298
Suspended solids	119-225	60-243	500	–	15	1,880-7,475

exceed the carrying limit of the coastal environment.

Table 5 compares effluent quality from operational shrimp farms with other types of wastewater (NEB, 1994). An analysis shows that in terms of quality, shrimp farm effluent is far less polluting both during operation and during harvest, than domestic wastewater that has undergone secondary treatment. From various observations, nutrient loads and dense phytoplankton in farm effluent also enhance the growth of aquatic species such as green mussels, oysters, cockles, horse shoe mussels and seaweed around the shrimp farming area providing ample evidence that such loadings do not exceed the carrying-capacity of water sources.

There are, however, many shrimp farms discharging to the coastal environment and it is useful to compare the total loadings with those from other sources to put the contribution of shrimp farm wastes in proper perspective. Table 6 compares the overall loadings from shrimp culture in each region of Thailand with those from the major river systems (DPC, 1996). The results of this analysis show that shrimp farms are not a major contributor to overall nutrient loads in the Upper Gulf of Thailand, both in terms of volume discharged and quantity of nutrient. Analysis for the southern coast which still use the high water exchange system, suggests that shrimp farms are more significant contributors to overall loads. However, farm wastes in these areas are diluted quickly due to the good circulation or flushing out to the deep sea. Considering the the total loadings in the country, shrimp farm effluent is still not a major cause of pollution to coastal environment.

7. Developed Culture Practices for Improving Environment

In order to solve environmental problems and to keep shrimp farming sustainable, Thai farmers have successfully developed their culture practices as follows :

Table 6 : Loadings from the major river systems compared with shrimp effluent loading

Major river areas	Annual discharge (million m^3/yr)	Total Nitrogen (ton/yr)	BOD (ton/yr)	Total Phosphate (ton/yr)	Nitrate (ton/yr)
Upper Gulf					
River discharge	57,550	64,736	115,704	14,777	13,865
Shrimp culture	64	345	350	19	2
Eastern coast					
River discharge	4,971	NA	17,829	575	1,544
Shrimp culture	742	3,137	4,155	164	196
Southern coast					
River discharge	15,230	8,831	15,297	2,623	15,297
Shrimp culture	1,109	10,083	8,537	576	NA
Total					
River discharge	77,751	73,567	148,830	17,975	30,706
Shrimp culture	1,915	13,565	13,042	759	198

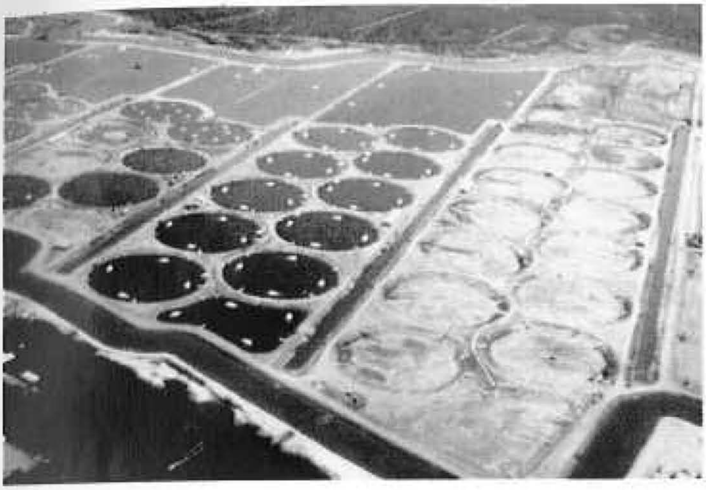


Fig. 1. Circular ponds ensure proper water circulation

Fig. 2. Pond dykes must be strong and well packed in order to prevent leakage

Fig. 3. Proper pond preparation ensures elimination of toxic gases such as ammonia, hydrogen sulphide and methane in the pond bottom

Fig. 4. After every crop, the fouled layer of pond bottom should be scraped off by bulldozer

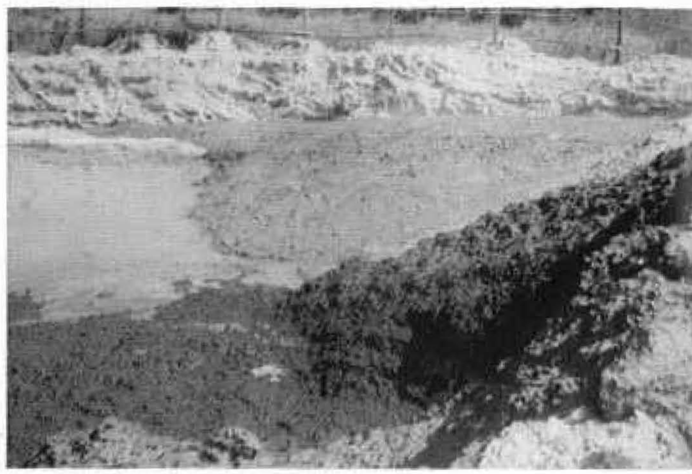


Fig. 5. Bottom deposits and soil removed from the ponds could be dried and treated in a treatment area

Fig. 6. Circular water movement in ponds is facilitated by heavy aeration which brings the solid waste to the centre of the pond

(i) ***Intensification:*** Semi-intensive technology, which is easily adapted to local conditions, is the most appropriate system at the initial period of shrimp culture development. After farmers have gained experience in shrimp farming and the related industries have been developed, this culture system should be intensified in order to increase country production without expansion of production areas. In some countries, semi-intensive culture, which generates less feed waste than intensive systems, still causes self-pollution. This is mainly caused by the inability of the farmers to carry out pond treatment / preparation before stocking, due to the lower level of the pond bottom in a tidal area, and the poor water circulation without efficient aeration in large ponds It is also impossible to remove the fouled substrate in a large pond with heavy machine as is done in the case of more efficient intensive ponds. After the ponds have been used for 6-8 years, the production of this system invariably goes down significantly and improvements are difficult.

(ii) ***Suitable pond design and construction:*** In order to facilitate the optimal water circulation in a pond, the shape of the pond should be square or round (Fig. 1). The optimal pond size is about 0.5 ha. The pond bottom level should be high enough to facilitate complete draining and drying between crops. Pond dikes must be strong and well packed in order to prevent leakage (Fig. 2). Import of clay or laterite from nearby area should be considered if the site is sandy or has acid sulfate soil. Generally, water storage ponds are necessary for good water circulation.

(iii) ***Proper pond preparation :*** Pond preparation is the most important operation in shrimp farming. Proper preparation ensures elimination of toxic gases such as ammonia, hydrogen sulfide and methane in the pond bottom which would have accumulated during the previous crop (Fig. 3). If possible, after every crop, the fouled layer of pond bottom should be scraped off by bulldozer and dried on pond dikes or removed by excavator to dry in the reserved area near the grow-out pond (Fig. 4). If the use of heavy machine is not practical in the rainy season, this fouled substrate can be partly sucked up by specially designed machines and transferred into the treatment pond for further drying and treatment (Fig. 5). After drying for about one month to eliminate the left-over toxic gases, lime should be applied before stocking. With this type of waste removal, water exchange could be reduced to the minimum thereby reducing the organic load discharged to the environment.

(iv) ***Proper water management:*** In order to maintain good water quality during low water exchange, circular water movement in ponds is facilitated by heavy aeration which brings the solid waste to the centre of the pond (Fig. 6). Shrimp tend to avoid living or feeding in areas of the ponds where high levels of waste have accumulated. Plankton blooms must be monitored and controlled carefully through regular recording of water colour, pH, alkalinity and transparency. It is now believed that the introduction of new water into the pond causes high mortality due to sudden change in water quality (physical,chemical and biological). Low water exchange also lessens introduction of viruses, other pathogens, disease carriers, ammonia and other toxic particles which are released by nearby farms, through the incoming water. If high water exchange system is still maintained, organic load in brackishwater sources will settle in the growout pond thus increasing the level of pond bottom and rapidity of pond deterioration. Even when the quality of existing pond water is poor owing to low water exchange, shrimp can gradually get adapted to this condition. Therefore, most of the intensive farmers in Thailand now prefer to reduce their water intake from external sources as much as possible, thus reducing waste discharged to environment. In order to keep the system closed from external pathogens and disease carriers, incoming water to growout pond should pass through a chlorination process in the reservoir.

(v) ***Closed culture systems :*** If ponds are located in unavoidable polluted areas or areas of high incidence of diseases, particularly along rivers and canals, farmers develop a closed culture system which does not require water exchange from external water sources for the entire duration of the growing period. This system must have reservoirs or water treatment ponds which generally occupy 20-30% of grow-out pond size, attached to the grow-out ponds. Clean water during the highest tide day is introduced only once (at the start of culture cycle) into the grow-out ponds and the reservoir. 10 ppm Benzalkonium chloride or hypochlorite is applied by spreading all over water area. Heavy aeration is also continuously applied for a few days in order to quickly eliminate chlorine gas and residue. Both ponds are later fertilized because water has became clear after chlorination. In order to keep water treatment system efficient, stocking density in this closed system should be limited at $30/m^2$ or at 6 ton/ha of production level. There is no water exchange within the process in the first month. In the second month, all water from the reservoir is added to fill the grow-out ponds while waste (bottom) water from the grow-out pond is pumped back at the rate of 30% every 10 days, through water supply/drainage canal, to this reservoir, which now serves as a sedimentation or settling pond. 30% water is exchanged on every 7th and 4th days during the 3rd and 4th months respectively. However the exchange regime also depends on the dissolved ammonia concentration in the grow-out pond which should not exceed 0.1 ppm. Organic loads and silt will settle in this sedimentation pond within 2-4 days before its surface water overflows to the second treatment pond (20-30% of grow-out pond area) for biological filtration. Living organisms such as phytoplankton and zooplankton are consumed by introduced fish and bivalves, e.g. tilapia, mullets, milkfish, green mussels, oyster, artemia, etc., in order to prevent overblooming of phytoplankton. Stocking densities of these plankton feeders depend on phytoplankton level in this pond. Green mussels are able to reduce 67% and 77% of amonia-nitrogen and BOD levels respectively within 24 hours. The clear surface water is then allowed to overflow into the supply canal where heavy aeration is applied in order to eliminate toxic gases. This recycled water is then pumped back into grow-out pond. Up to harvesting time, pond salinity, which gradually increases through evaporation, does not exceed 40 ppt because the initial salinity would be about 10-15 ppt. In an emergency, when new water is required for dilution of pond water, if the pond salinity rises above 40 ppt, the incoming water must be chlorinated separately in a spare pond. In case many grow-out ponds use the same water treatment ponds, wastewater from an infected pond must not be pumped to this common facility. All water released to rivers/canals must always be treated and disinfected by 300 kg/ha chlorine. In some cases the water may be used for two production cycles before being replaced.

(vi) ***Freshwater culture systems :*** In these systems, shrimp are cultured at very low salinities (0-5 ppt) in essentially freshwater ponds which do not exchange water. Most of *P. monodon* freshwater farms are developed from catfish and *Macrobrachium* ponds. Concentrated saline water (100-150 ppt) is bought from salt farms and added to the chlorinated freshwater pond to achieve a salinity of around 5 ppt with 0.35 m depth at the initial period. Within the first month after stocking, pond is gradually filled up with freshwater which makes salinity reduced over the culture period to around 0 ppt at harvest time. In freshwater system, shrimp will be usually harvested within 3 months at averaged 20 g size otherwise mortality may occur. This will significantly reduce the pond deterioration because feed consumption is far less from 4-month culture. During harvest, pond water which is not harmful to surrounding environment, is then released to natural water bodies. Only pond bottom soil has become salty which will be convenient for farmer to introduce less saline water to the pond in order to keep salinity level at 5 ppt in the next crop. Fouled pond bottom is mechanically removed to reserved area once every two years as the deterioration is much less than that in brackishwater culture.

8. Government Policies towards Reducing Pollution from Coastal Aquaculture

The policies aim to efficiently utilise coastal areas for shrimp culture taking into consideration the local economic and social development, conservation, impacts on the coastal environment and conserving fresh and seawater resources. Systematic management of effluent from culture areas is also a priority. The government activities carried out to improve the environmental performance of shrimp farms are as follows:

(i) ***Dredging ditchs and canals to increase the supply of water*** : Sedimentation in water supply canals (partly as a result of solid waste discharges from shrimp farms) has led to restricted water flows in supply canals. A lot of budget has been allocated to dig out shallow canals throughout the country since 1992.

(ii) ***Reducing costs of production :*** The Department of Fisheries carries out research on farm management techniques to establish optimal cultivation procedures which minimise environmental impacts. Research areas include management practices, feeding, waste water treatment, production of fertiliser from bottom sludge, environmental monitoring, training and technology transfer.

(iii) ***Improved culture techniques*** : Model demonstration farms were constructed to promote good shrimp culture practices among farmers in various regions.

(iv) ***Designation of shrimp culture zones :*** This measure aims at ensuring development of shrimp culture in appropriate areas.

(v) ***Quality control of shrimp larvae :*** To maintain the quality of shrimp larvae, the Department of Fisheries provides certification for hatcheries producing good quality larvae. In 1989, there was a ministerial regulation which required all hatcheries to register and apply for permit to operate.

(vi) ***Registration of shrimp farmers:*** Under the Fisheries Act, all shrimp farmers are required to register their farms. The farmers who owned over 8 ha, have to obtain the annual operating licenses. Farmers who are not registered have no right to assistance from the government for monitoring water quality, antibiotic residue, disease diagnostics, export certification for TED issue and product quality certification. Unregistered farmers also cannot claim compensation for damage caused by floods or other natural hazards.

(vii) ***Seawater irrigation:*** Seawater irrigation systems were recommended as a potential answer to self-pollution problems threatening the industry and to provide better water circulation to the supra-tidal areas behind the mangroves. Self-pollution occurs when farms discharge water into canals used for water supplies by other shrimp farms. Seawater irrigation system aims to solve this problem by designing farm layout so that intake and drainage canals are kept separate. These projects therefore involve areas of land to be designated as shrimp culture zones, the construction of intake and discharge canals and the construction of intake and discharge water treatment systems. Problems such as redesigning existing shrimp farms and removing other users from zones make the practical implementation of irrigation systems on private land difficult, particularly if some farmers have to give up productive land to create common treatment facilities. The successful operation of seawater irrigation systems requires co-operation of all the farmers involved. The currently proposed seawater irrigation projects cover the area of 8,780 ha and some of them have been constructed.

(viii) ***Control of feed quality:*** The Feed Quality Control Act required all feed manufacturers to register and set quality standards for pre-mixed and ready mixed feeds. The percentage of protein, fat, fibre and moisture should be in accordance with the trade name, type and size of feed or the age of aquatic animals for which they are intended.

(ix) ***Control of chemicals and hazardous substances :*** The control of some chemicals and toxic substances used in aquaculture is now under the responsiblity of the Department of Fisheries, instead of the Food and Drug Administration, Ministry of Public Health.

(x) ***Co-operating with the private sector to provide services to farmers :*** The DOF provides a service to shrimp farmers on the examination of toxic substances and antibiotic residue in shrimp. A cabinet resolution in 1993 designated the DOF a competent authority to issue certificates of hygiene for fisheries exports, particularly frozen shrimp products. In 1994, DOF started the Development of Raw Materials and Fishery Products Inspection System Project under which raw materials and fishery products for export must be certified by the DOF to ensure that the products meet the inspection standards of foreign countries, particularly the European Community, Japan and USA. The project included the establishment of Raw Material Inspection Centres in 20 provinces and Fisheries Product Inspection Centres in 4 provinces. Membership of the certificaion scheme is voluntary for shrimp farmers and is independent from farm registration procedure. The main incentive for farmers to join this is that certification from the DOF enables the farmers obtain a higher prices for their shrimp. When a shrimp farmer joins the certification programme, the DOF inspect the farm and grade it in to Grade A, B or C based on the facilities and management practices used. The DOF can then recommend to the processors the names of the farms which are able to consistently produce shrimp of required standard.

(xi) ***Monitoring of environmental impact :*** The DOF regularly investigates water quality, soil quality and other environmental parameters as well as shrimp quality as part of its plans to improve larval quality and standard of shrimp farming.

(xii) ***Designation of effluent standards:*** Waste waters from shrimp farms are regulated under a regulation of the Fisheries Act. All shrimp farmers need farm registration and the farmers whose culture operations are more than 8 ha also require licensing. Licensed shrimp farmers have to comply with the following regulations :

Table 7 : Environmental management of coastal aquaculture in NACA countries

	Registration of farms	EIA	Specific aquaculture legislation	Effluent standards	Monitoring	Effluent treatment requirement
Bangladesh	No	No	No	No	No	No
Cambodia	No	No	No	No	No	No
China	Yes	No	No	No	No	No
Hong Kong	Yes	Yes	No	Yes	No	Yes
India (some states)	Yes	Yes	Yes	Yes	No	No
Iran	Yes	No	No	No	No	No
Indonesia	–	–	No	Yes	No	No
Korea	Yes	No	Yes	Yes	Yes	Yes
Malaysia	Yes	Yes	Yes	No	No	No
Myanmar	Yes	No	Yes	No	No	No
Philippines	Yes	Yes	No	Yes	Yes	No
Sri Lanka	Yes	Yes	No	Yes	Yes	Yes
Thailand	Yes	No	No	Yes	Yes	Yes
Vietnam	No	No	No	No	No	No

Table 8 : Effluent standards for coastal waters in NACA countries

Parameter	Hong Kong	India (some states)	Korea	Philippines	Thailand	Sri Lanka
BOD (mg/l)	10-40	20-50	–	3	10	50
COD (mg/l)	50-85	75-100	–	–	–	250
pH	6.0-10.0	6.0-8.5	–	6.5-8.6	–	6.0-8.5
Suspended solids (mg/l)	25-40	100	–	30% increase	–	100
Temperature (°C)	40-50	–	–	3° max. rise	–	35
Total nitrogen (mg/l as N)	10-50	2.0	–	–	–	2.0
Total phosphorus (mg/l as P)	5	–	–	–	–	–
Phosphate (mg/l)	–	0.2-0.4	–	–	–	2.0
Total ammonida (mg/l as N)	–	0.5-1.0	–	–	–	–
Dissolved oxygen (mg/l)	–	>3	–	5	–	–
Coliform (MPN/100ml)	1,00	–	<70	70	–	–

- Farm effluent water must have a BOD_5 less than 10 mg/l
- Pond sludge and mud should not be discharged to natural water sources or public areas
- Salt water should not be discharged into public freshwater
- Farms with pond areas greater than 8 ha should have effluent treatment ponds of not less than 10% of pond area.
- New effluent standard has been recommended for law enforcement (DPC, 1996) as follows:

Salinity	-	1.5 ppt in freshwater
	-	maximum 10% change in coastal water
pH	-	6.5-9.0 in freshwater
	-	7.0-8.7 in coastal water
Dissolved oxygen	-	greater than 4.0 mg/l
BOD_5	-	10 mg/l
Suspended solids	-	100 mg/l
Total ammonia	-	0.7 mg/l in freshwater
	-	1.5 mg/l in coastal water
Nitrite	-	0.02-0.2 mg/l as N in freshwater
	-	0.2 mg/l as N in coastal water
Nitrate	-	20 mg/l as N in freshwater
	-	not necessary in coastal water
Transparency	-	60 cm
Total nitrogen	-	not necessary in freshwater
	-	4.0 mg/l in coastal water
Total phosphorus	-	not necessary in freshwater
	-	0.4 mg/l in coastal water

9. Environmental Management of Coastal Aquaculture in other NACA Countries

In order to establish how other Asian countries approach environmental management of coastal aquaculture, a questionnaire was sent out to 13 countries in the NACA network. The results are summarized in Tables 7 and 8.

References

Barg, U.C., 1992. Guidelines for the promotion of environmental management of coastal aquaculture development. *FAO Fisheries Technical Paper*, No. 328, FAO, Rome.

DOF, 1995. Statistics of shrimp culture in 1994. Department of Fisheries, Ministry of Agriculture and Co-operatives, Bangkok, Thailand.

DPC, 1996. A survey of water pollution sources from coastal aquaculture. Final report submitted to the Department of Pollution Control, by. Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand. November, 1996.

FAO/NACA, 1995. Regional Study and Workshop on the Environmental Assessment and Management of Aquaculture Development (TCP/RAS/2253) : NACA environment and aquaculture development series no. 1. Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand.

Aquaculture Asia, 1996. The mangroves : finding a way out of the thicket of complications. From the editors desk of Aquaculture Asia magazine, Vol 1, No.2. October-December 1996.

Menasveta, P, 1996. Mangrove destruction a shrimp culture systems. Aquatic Resourc **Reseach Institute, Chulalongko** University, Bangkok, Thailand.

NEB, 1994. The environmental management coastal aquaculture. An assessment shrimp culture in Southern Thailand. Fin report submitted to the Office c Environmental Policy and Planning, b Network of Aquaculture Centres in Asia Pacific. January, 1994.

2

Environmental Issues in Indian Freshwater Aquaculture

S. AYYAPPAN and J. K. JENA

Central Institute of Freshwater Aquaculture
Kausalyaganga,
Bhubaneswar - 751002, India

1. Introduction

Aquaculture is assuming increasing importance in recent years on a global basis including the Indian subcontinent. With possibilities of obtaining high productivity levels among different farming system, there has been a flux between the farming practices and aquaculture is receiving greater investments both in public and private sector. The contribution of freshwater aquaculture to the total fish production has risen steadily from 17% a decade back to over 30% at present. It is common knowledge that with stagnating trends of marine fisheries as well as inland capture fisheries production levels, freshwater aquaculture is an attractive option for increasing fish production in the country. This substantiated by the growth rates of over 5% over the last few years. The sector, with the necessary R&D back-up for culture of different components of carps, catfishes, prawn

AQUACULTURE AND THE ENVIRONMENT
ISBN 81-85340-17-X

and molluscs, entrepreneurial enthusiasm and the governmental support, is poised to realize the potential of about 4.5 million metric tonnes in the coming decade.

As with any developed process, freshwater aquaculture development too has several environmental issues if not concerns to be deliberated upon. They include biodiversity of fishes, land-water interactions, environmental pollution, feed and fertilizer-related water management, import of exotic fish and shellfish species and their quarantine, water budgeting and management, comparative energy budgeting for different farming systems, human pathogens associated with fish cultured in waste waters, fish marketing and hygiene, etc. It may be mentioned that freshwater aquaculture being compatible with other farming systems is largely environment-friendly and in fact provides for recycling, utilization and even treatment of organic wastes. Pollution due to effluents from the freshwater aqualculture systems is yet to assume any considerable proportions. However, due attention is being given to this aspect too in view of intensification of aquaculture practices in recent years. The paper discusses these issues in the context of the significant growth trends of freshwater aquaculture in the country.

2. Biodiversity of Fish Species

India has a rich and diverse fish fauna of 2200 species which is about 11% of the global fish faunal resources (about 20,000 fish species) occurring in cold and warm waters, both freshwater and marine. Of the country's fish species, 24.7% live in warm freshwaters, 3.3% in cold waters, 6.5% in estuaries and 65.5% in the sea. Since the past several years, indiscriminate fishing, habitat destruction, degradation of water quality through pollution, construction of dams and barrages across the rivers and deforestation resulting in siltation and rise of river beds have been threatening the fish biodiversity. The populations of some of the economically important fishes inhabiting the natural waters like carps in the River Gange catfishes in marshy lands, mahseers in cold wat rivers, streams and reservoirs, migratory hilsa Hooghly river are declining over the years, revealed from the production trends of these fishe It has been reported that out of 79 threatene species listed so far, 63 species belong to freshwat (46 from warm water and 17 from cold wate Among the listed threatened species (Table 1 species like *Ompok pabda*, *O. pabo*, *Tor mussull* in warm water and *Gymnocypris biswasi* in co water have become endangered (Mahanta *et a* 1994).

India is known for its rich and diverse populati of gangetic resources of value. Even so, over 3 exotic varieties have been introduced into t country so far (Jhingran, 1989). While most them are ornamental fishes which remain more less confined to the aquaria, some have bee introduced into the aquaculture systems and op waters. Among the species introduced, while few have proved to be a boon to the aquacultur the accidental or deliberate introduction of som others has caused havoc to the aquatic environme as a whole. The tilapia, *Oreochromis mossambic* which was introduced into the country durin 1952 made its presence in almost all t waterbodies within a few years. The main attracti for its introduction was its pond breeding a omnivorous feeding habits. However, its ear maturation, prolific breeding and voracious feedi habits not only found to adversely affect t growth of carps in polyculture system, but al eliminated were other fishes including Gange carps in a number of reservoirs. The effects we well reflected in fisheries of many reservoirs Tamil Nadu *viz.*, Vaigai, Krishnagiri, Amarava Uppar and Pambar. Similarly, introduction *O. mossambicus* in Jaisamand lake of Rajasth not only resulted in reduction of average weight major carps, but also posed a threat to species li mahseers (*Tor tor* and *T. putitora*) which are the verge of extinction (Bhatnagar, 1995). prolific breeding resulting in inadequate grow

Table 1. List of threatened freshwater fishes of India

Warmwater Fishes		Location
Endangered		
1. *Ompok pabda*	-	Ganga, Brahmaputra river system
2. *Ompok pabo*	-	Freshwaters of Assam, West Bengal
3. *Tor mussullah*	-	Cauvery, Bhawani river
Vulnerable		
1. *Ailia coila*	-	Freshwater of Krishna, Darjeeling, Assam, Orissa, Madhya Pradesh
2. *Anguilla bengalensis*	-	Throughout India
3. *Bagarius bagarius*	-	Ganga river and its tributaries
4. *Eutropiichthys vacha*	-	Freshwaters of Punjab, Uttar Pradesh, Bihar, Orissa
5. *Labeo dyocheilus*	-	Doon valley, Kashmir, Poonch, Assam
6. *Ompok bimaculatus*	-	Freshwaters of Kashmir, Punjab, Uttar Pradesh, Bihar, Manipur, Assam, West Bengal.
7. *Puntius sarana*	-	Throughout India except Peninsular India
8. *Semiplotus semiplotus*	-	Freshwater of Assam and Darjeeling
9. *Cirrhinus cirrhosa*	-	Cauvery, Godavari, Krishna river system, Narmada & Pench river in Madhya Pradesh
10. *Osphronemus nobilis*	-	Rivers of north east Bengal and Assam
11. *Labeo dero*	-	All along Himalayan foot hills, Darjeeling, West Bengal
12. *Labeo dussumieri*	-	Western Ghats upto North Canara
13. *Osteobrama belangeri*	-	Manipur (previously found in Bengal from where it has disappeared)
Rare		
1. *Horaglanius krishnai*	-	Kottayam, Kerala State
2. *Schistura sijuensis*	-	Throughout India
Indeterminate		
1. *Notopterus chitala*	-	Freshwater rivers, streams of India
2. *Pangasius pangasius*	-	Freshwater of Uttar Pradesh, Bihar, Madhya Pradesh, Darjeeling, Assam, Orissa and Madras
3. *Tenualosa ilisha*	-	Indian oceans, coastal waters, estuaries, rivers
4. *Thynnichthys sandkhol*	-	Freshwater of South India, Krishna and Godavari river system
5. *Tor khudree*	-	Freshwater of Uttar Pradesh, Orissa, Kerala Peninsular India
6. *Balitora brucei*	-	Darjeeling, Assam
7. *Barbus dukai*	-	Eastern Himalaya and Assam
8. *Chagunius chagunio*	-	Brahmaputra and Ganga drainages along the Himalaya foot hills
9. *Crossocheilus latius*	-	Drainages of the Ganga and Brahmaputra in river drainage in Orissa and Western ghats, south to the head waters of Krishna river
10. *Gadusia chapra*	-	Ganga, Brahmaputra river system, Mahanadi river, Bay of Bengal
11. *Glyptosternum maculatum*	-	Sikkim
12. *Labeo fimbriatus*	-	Northern hills of Nepal border, Sindh, Punjab, Orissa, Southern India except Malabar and Canara
13. *Labeo gonius*	-	Freshwater of Assam, Darjeeling, West Bengal, Bihar, Uttar Pradesh, Orissa
14. *Mastocembalus armatus*	-	Throughout India
15. *Mystus tengara*	-	Through North India
16. *M. aor*	-	River Ganga, Yamuna, Brahmaputra, Mahanadi
17. *Nandus nandus*	-	Throughout India
18. *Olyra logicaudata*	-	Base of Darjeeling, Himalaya, Meghalaya and Assam
19. *Psylorhynchus homaloptera*	-	Assam, Brahmaputra drainage
20. *Puntius carnaticus*	-	Freshwater of Nilgiri, Wynaad, Canara hills
21. *Puntius conchonius*	-	Brahmaputra, Uttar Pradesh, Bihar
22. *Rasbora rasbora*	-	Freshwaters of all the Indian States, most common in the valley of Ganges
23. *Setipinna phasa*	-	Ganga river system and Orissa
24. *Silonia childreni*	-	Freshwaters of Krishna, Godavary, Cauvery river system
25. *Silonia silondia*	-	Freshwater of Punjab, Uttar Pradesh, Bihar
26. *Tor mosal*	-	Hill streams of Himalayas
27. *Xenentodon cancila*	-	East coast of India
28. *Bengala elonga*	-	Bihar, Uttar Pradesh, West Bengal, Assam
COLDWATER FISHES		
Endangered		
1. *Gymnocypris biswasi*	-	Chusul, Ladakh
Vulnerable		
1. *Tor putitora*	-	All along the Himalaya, Darjeeling
2. *Psilorhynchus balitora*	-	Yamuna river in Delhi, river Gomati
3. *Raiamas bola*	-	India, confined to the hilly areas of the northern provinces (Haryana, Himachal Pradesh, Uttar Pradesh, Bihar, Assam, West Bengal, Orissa)
4. *Schizothorax kumaonensis*	-	Kumaun hills
Indeterminate		
1. *Botia almorhae*	-	Kumaun hills specially in Kosi river
2. *Lepidophygopsis typus*	-	Periyar river and Lakes of Kerala
3. *Noemacheilus rupicola*	-	West Himalaya, Kumaun through Garhwal Himalaya to Yamuna Sutlej and Beas drainages of Himachal Pradesh
4. *Tor tor*	-	Uttar Pradesh hills, Darjeeling, Madhya Pradesh, Bihar, North Bengal, Assam
5. *Noemacheilus clangatus*	-	Meghalaya near Shillong
6. *Schizothorax richardsoni*	-	Sub-Himalayan range
7. *Puntius chillinoides*	-	Himalayan foot hills, Ganga river system
8. *Schizothorax plagiostomus*	-	Along the Himalayan foot hills
9. *S. progastus*	-	Jammu and Kashmir Valley, Ganga river in Uttar Pradesh and Brahmaputra river in Assam
10. *Schizothoraichthys esocinus*	-	Indus river and its tributaries in Ladakh & Kashmir
11. *Schizothoraichthys longipinnis*	-	Kashmir valley and Indus river system
12. *Schizopygopsis stolickekae*	-	Leh and headwaters of Indus, also tributaries of the Yarkand and Oxus river

Source: Mahanta *et al.* (1994) and Anon (1994) prompted the Fisheries Research Committee of India to ban its propagation in 1959. In spite of such regulations, the species has spread itself not only into most of the freshwater reservoirs and other water bodies but also has found its way into many brackishwater bodies of the country. The fish is considered as a pest and menace to the freshwater aquaculture development.

Silver carp, *Hypophthalmichthys mollitrix* was introduced in India in 1959 and unlike tilapia, it has not strayed into many reservoirs. However, silver carp has attracted more attention from the ecologists and fishery managers generating more animated debates. Most spectacular performance has been reported from Govind Sagar reservoir, where after an accidental introduction, the fish formed a breeding population and brought about a phenomenal increase in fish productivity. This drastically reduced the fishery of the native catla and *T. putitora*. In 1974-75, when silver carp was not here, *T. putitora* contributed as much as 20.62% of the total yield, but constituted only a meagre amount of 2.23% during 1984-85 with silver carp introduction. Common carp, *Cyprinus carpio* was also responsible for a similar situation (Johal and Tandon, 1983). The near extinction of snow trout, *Schizothorax* spp. and *Oreinus sinceatus* is also attributed to the exotic common carp. The mirror carp, a strain of common carp has already jeopardised the population of a number of native fish species after its introduction in some upland lakes of Kumaon Himalayas, the Dal lake in Kashmir, Govind Sagar in Himachal Pradesh and reservoirs of the north-east. In Dal lake, common carp found a favorable environment by virtue of its shallow lake basin, extensive submerged vegetation and rich food resources. The fish propagated profusely by virtue of the specific ecological advantage and threatened the fishery of indigenous snow trout's like *Schizothoraichthys nigor*, *S. esocinus* and *S. carvifrons*. The extinction of *Osteobrama belangeri* in Loktok lake of Manipur has also been documented due to the exotic common carp.

Recently, *Tilapia zilli* a herbivorous cichlid has been introduced in the Indira Gandhi Canal of Rajasthan for controlling the aquatic weeds (Bhatnagar, 1995). The control of floating macrophytes like *Eichhornia* and emergent vegetation like *Typha* by *T. zilli* is doubtful (Sreenivasan, 1995). Besides this when grass carp, another exotic species which has proved to be a voracious feeder of many aquatic vegetation and native *Puntius pulchelus* which too is a potential species for weed control are already available in our waters, the introduction of *T. zilli* needs to be evaluated.

Import of seed of sea bass and sea bream from abroad for cage culture in Indian waters is being proposed for which there is a justifiable objection form the environmentalists, that has resulted in a stay order by the Calcutta High Court (Sreenivasan, 1995). The introduction of Nile perch (*Lates niloticus*) into the Lake Victoria would be an apt comparison, which has resulted in extinction of about 50% of the 400 indigenous species available in the lake.

India possesses good varieties of catfishes like *Clarias batrachus*, *Heteropneustes fossilis*, *Mystus seenghala*, *M. aor*, *M. gulio*, *Wallago attu*, *Silonia silondia*, *Pangasius pangasius*, *Bagarias bagarias*, *Ompok bimaculatus*, etc. that are potential candidate species for culture. Introduction of exotic catfish species like *Ictalurus spp.* needs to be considered in details including the possible hazards of introducing associated viral pathogens.

The African catfish, *Clarias gariepinus*, is another exotic catfish which has made its way into the Indian waters through Bangladesh. The availability of the species has already been reported form Orissa, Bihar, West Bengal and Andhra Pradesh. The species which grows to large sizes (beyond 1.5 m/10 kg) is known to be highly predatory as also cannibalistic. The consequence could be disastrous when they find entry into the neighboring ponds and any other open waters like major riverine and reservoir systems.

Japanese rainbow trout and sock eye salmon were imported from Japan and Canada respectively into the Nilgiris streams of Tamil Nadu. Not only they did not survive, but brought in diseases like whirling disease, white spot (Ichthyophthyriasis), costiasis, etc. for the first time in the Nilgiris.

It is learnt that the exotic carp bighead, *Aristichthys nobilis* has made its entry into the Indian waters from Bangladesh. According to the available information, the fish is now available in states like West Bengal, Bihar, Orissa and Andhra Pradesh, and some private hatcheries of West Bengal are producing its seed on a large scale. In spite of the instructions issued by the Union Department of Agriculture to the various States requesting them to destroy the fish and not to encourage its culture, the species is spreading into other States too. It may result in threatening the fishery of catla in our reservoirs and rivers.

3. Fish Genetics Research - Implications

Genetic improvements in fish species could be brought about through genome manipulations, incorporation of an external gene for producing transgenic varieties or hormonal manipulations to achieve higher growth rates. The biohazards of genetic manipulation in the form of mutants, deformed specimens and those with an imbalance in the gonadosomatic functioning are to be considered in breeding programmes. A major aspects of concern in farm breeding programmes is with regard to inbreeding depression that has not taken care of by the fish farmers in the country. Success in milt cryopreservation offers a tool in brood stock replenishment and improving progeny. Indiscriminate use of hormones for breeding, production of monosex populations for somatic growth is an issue to be considered in the wake of intensifications of fish culture practices in recent years.

4. Land-water Interactions

The unplanned expansion of aquaculture in some parts of the country has resulted in degradation and in certain cases destruction of the natural resource systems and environment in which aqua culture is practised. Conversion of over 60,000 ha of paddy fields into aquaculture ponds in Andhra Pradesh over the last two decades, as also unplanned conversion of Kolleru lake area into fish ponds are a few examples.

In India, nearly 5334 million tonnes of soil are eroded from the cultivable lands and forests annually. On crop land, the erosion can range from 7 to 120 t/ha/yr. The rivers carry an approximate 2050 million tonnes of soil of which nearly 480 million tonnes is deposited in reservoirs and 1,570 million tonnes is washed into the sea every year (Gupta, 1975). For example, River Ganga with only a drainage basin of 1.1 million sq. kms carries an annual sediment load of 1.46 billion tonnes of soil. The siltation of the rivers and reservoirs not only results in destruction of breeding grounds of several fishes but also leads to reduction of overall productivity. The deforestation of catchment area resulting in sitation and often change in river course have also affected the fish catch.

Though most of the aquaculture farms use surface run-off water, ground water and spring water are also used during lean season that cause depletions in ground water table. Further, injudicious exploitation of underground freshwater may lead to salination and soil degradation. Salination of soil due to effluent discharge from freshwater prawn hatcheries being established in large numbers in recent years is also an area of concern.

5. Environmental Pollution

The rapid industrialization and population explosion have resulted in ever-increasing disposal of toxic wastes and sewage respectively to the open water bodies, polluting the major river systems, that are ultimately used as source of water for aquaculture. It is estimated that nearly 33 million tonnes of sewage are generated daily in India (1981 census). The amount of sewage pollution in the country is very well reflected by the River Ganga, in which more than 70% of the pollution load is contributed by sewage. The sewage generated in 692 cities and large towns all along the basin is estimated at 1,528.1 million tonnes. The resultant BOD load in Ganga basin is estimated at 2,504 million kg/day of which domestic source contributes 1,338 million kg/day. The sewage obtained from the highly industrialized cities like Delhi, Calcutta, Kanpur, etc. is also found to contain synthetic detergents to the tune of 0.02 - 2.0 ppm (Jhingran, 1991). Sewage disposal today is the foremost problem in many of our water courses. Most of the treatment plants remove a good part of the solid particles, but only a part of phosphates and nitrates. This leads to eutrophication in water bodies, low dissolved oxygen level and high BOD levels.

In India, although the industrial development has not reached the level attained in the developed countries, the toxic compounds, hitherto unknown, are being detected in increasing numbers in our water courses owing to their indiscriminate application. It is largely because the production of chemicals resulting in the generation of toxic and hazadous substances has been continuously on increase for last three decades (Table 2). Among the industrial effluents discharged into the water bodies, while the pulp and paper, dairy, distillery and cotton textile industries generate putrescible organic wastes, the industries manufacturing organic chemicals, pesticides, fertilizers, dyes and pigments, paints and varnish, nonferrous metals and steels, etc. generate toxic and hazadous wastes (Jhingran, 1991). These industrial effluents even at comparatively low concentrations cause menace to aquatic environments and the biotic communities including fish and ultimately affect man through the food chain. The industrial effluents contain wide variety of chemical toxicants and heavy metals. Apart from this, they contribute substantially to the BOD loads. For example, the fertilizer wastes at Allahabad have adversely affected the population of carps, catfishes and murrels. Plankton and benthos are known to disappear upto a strech of 300 km downstream, due to high pH and ammonia toxicity. Besides this, a few other reports are also available regarding fish mortality due to hazadous and toxic wastes discharged from various industries which are illustrated in Table 3.

Aquaculture at present is characterised by indiscriminate use of a wide spectrum of organic and inorganic chemicals to prevent or control the diseases. Further, the major source of pesticides in

Table 2. Growth of industries generating hazardous wastes

(Production in thousand tonne)

Industries	1960	1970	1980	1986-87
Pesticides	1.46	3.0	40.68	56.2
Dyes and pigments	1.15	13.55	30.85	-
Organic chemicals & petrochemicals	580	17,100	24,100	42,500
Fertilizers	153	1059	3005	7000
Steel (Ingots)	1500	3400	8000	9000
Non-ferrous metals	8.5	34.6	82.9	123.4
Caustic soda	101	304	457	764
Pharmaceuticals	1.23	1.79	5.07	-

Source: Jhingran (1991)

Table 3. Some fish kill incidences in Indian waters

Place	Year	Pollutants
Kankarai lake, Ahmedabad	1982	Domestic
Naini lake, Naintal	1980, 1981	Domestic waste
R. Gomti, Lucknow	1983, 1984, 1986	Distillery waste
R. Chaliyar, Alwaye	1974	Pesticide
R. Tungabhadra, Harihar	1984	Rayon polyfibre
R. Ganga, Monghyr	1968	Oil refinery
R. Adyar, Madurai	1981, 1982	Tannery
Rihand reservoir	1970, 1978, 1980	Chemical and thermal effluents

Source: Jhingran (1991)

most o the water bodies is the agricultural run-off. The production and consumption of pesticides have been strikingly increasing ever since they were first introduced. Sharma (1987) reported that 44 kinds of pesticides are in use in the country. The average consumption of pesticides in our country increased from 3.2 g/ha in 1954-55 to 336 g/ha in 1980 (Chottoraj, 1987). The increasing use of pesticides and insecticides in the agriculture system, for example, to the tune of 25,000 tonnes only in the State Andhra Pradesh, is polluting the major water system due to surface run-off that is ultimately used as a source of water for aquaculture. Further, it is reported that about 2600 tonnes of pesticides are used in an year in the Ganga basin. A good part of its is bound to enter the river system and subsequently the food chain of the fishes in the river itself as also in aquaculture farms drawing water from the reverine source. The demand for pesticides in the year 1983 and 1987 were 72,000 tonnes and 100,000 tonnes respectively and it is estimated to reach 200,000 tonnes by the turn of the century. With the intensification of agriculture sector, the use of pesticides has reached as much as 1490-1870 g/ha in USA and Europe, providing basis for their increasing use in our country in the coming years. Besides this, as the country does not possess at present an alternative sound method for control of pests like biological control, the projection given seems to be realistic.

Among the insecticides, organochlorines (DDT, DDD, Aldrin, Dieldrin, Toxophane, etc.) are most widely used, sharing about 40%, followed by organophosphates (Malathion, Parathion, Methyl parathion, Fenthion, Thimet, etc.) and carbamates (Sevin, Sevimox, Carbofuran, Carbaryl, etc.). Many of these pesticides/insecticides are non-biodegradable with slow decomposition rates. Highly toxic non-biodegradable chlorinated hydrocarbon and organophosphorus pesticides not only accumulate in the aquatic biota but are often biologically magnified through food chain and ultimately affect the human population. Moreover, they often combine with other compounds in the environment to produce additional toxins (Bandyopadhayay, 1995). Among the toxicants used, organochlorines and carbamates are most toxic and found to persist in soil and water for long time. For example, DDT and DDD have half life of 10-14 years and DDE has been known to have existed for 10 years, and aldrin and dieldrin require about 2.5 years for 95% degradation in soil (Chottoraj, 1987). Further, the carbamate insecticides though known to be less persistent than the organochlorine compounds, are highly toxic to wide varieties of invertebrates such as insects, prawns, crabs, and crey fishes. The study showed that both finfishes and shellfishes are extremely sensitive to chlorinated hydrocarbons and die from suffocation due to interference with oxygen uptake at gills as well as effect on central nervous system (Rudd, 1964). It is proved these chemicals destroy larval stages of various aquatic food organisms as also depress photosynthesis of plankton (Odum, 1971).

High doses of pesticides cause oedema especially at the base of the secondary lamellae due to increased capillary permeability. Under sublethal or chronic exposures, the changes observed in gills are swelling of lamellar epithelium, necrosis, hyperplasia, epithelial lifting, cell swelling and hyper secretion of mucus. Studies with endosulfan by Najmi *et al.* (1992) showed rupture of epithelial cells of mucosal folds of *Clarias batrachus*. Experiments conducted by Dutta *et al.* (1992) showed malathion exposure to *Heteropneustes fossilis* causes formation of two new proteins of very low mobility in blood serum associated with noticeable differences in RBC and WBC counts. Liver being the primary organ for detoxification of organic zenobiotics, the pesticides tend to accumulate to a high concentration in it resulting in focal necrosis, swelling, pyknosis, cytoplasmic vaculation, etc. Studies conducted on tilapia, *O. mossambicus* with five chlorinated hydrocarbons DDT, BHC, Endosulfan, Sonatox and Termax, concluded that aquatic environment contaminated with pesticides gradually imports abnormalities in the brood fish causing mortality of spawn, fry and fingerlings (Pandey and Bhattacharya, 1995). Sukumar and Karpagaganapathy (1992) working with *Colisa lalia* showed decline in number of mature oocytes followed by retrogressive nature of ovary, hypertrophic and wrinkled lamigenous lamellae when exposed to carbofuran.

Some pesticides such as DDT and BHC even at very low concentrations have been found to be biomagnified by the aquatic food chain ending up in very high levels in fish tissues. Studies carried out at CIFRI have shown biomagnification of DDT in plankton, fish, gastropods and bivalves from Hooghly estuary in the order of 2500, 7500, 3660 and 15800 times of the ambient levels of DDT in water. Another classical example of biomagnification of DDT has been presented by Woodwell *et al.* (1967) as follows: Water (0.000005 mg/l) (Plankton 0.04 mg/l) - Silverside minnow (0.23 mg/l) - Sheephead minnow (0.94 mg/l) - Pickerel (predatory fish) 1.33 mg/l) - Needle fish (predatory fish) (2.07 mg/l) - Heron (3.91 mg/l) - Herring gull heron (3.57 mg/l) - Herring gull (scavanger) (16 mg/l) - Fish chawk (Osprey) egg (13.8 mg/l) - Margemer (fish eating duck) (22.8 mg/l) - Cormorant (feeds on larger fish) (26.4 mg/l). It is evident from the above fact that the concentration factor (ratio in organisms to water) is about half million times for fish eaters.

The indiscriminate use of antibiotics in aquaculture to combat the disease problems without understanding their modes of action is another area of concern today. At present, an array of wide spectrum antibiotics are used in aquaculture to prevent or control several diseases. Most of the drugs are bacteriostatic where, bacterial multiplication is inhibited. Further, the prolonged, repeated and widespread use of antibiotics lead to the development of resistance in bacterial populations. In the same way, the rotating use of several antibiotics contributes to multiple drug resistance patterns. In aquatic system, the antibiotics are applied either in the medium or through feed unlike the direct administration to the infected ones only in case of terrestrial animals. In such cases, the organisms, both infected and healthy ones are subjected to the antibiotics administration and thereby stress. It has been reported that the antibiotics not only affected the physiological state and further the immune system of the animals but also result in bioconcentration and later in biomagnification in the higher trophic levels. A study showed that a congeneric derivative of the polycyclic nophthacane carboxamine, used extensively in aquaculture not only as prophylactic but also in controlling several bacterial diseases at present, resulted in 60% reduction in standard metabolism and about 50% reduction in protein synthesis in case of carps at the end of 96 hours of administration at 24 h interval dose frequency (Rao, 1995). Studies also showed the ability of antibiotics to bind with a number of elements, particularly metal ions, thereby affecting the modes of action and often become ineffective in its bacterial action.

6. Supplementary Feeding - Issues

The profitability of any modern and scientific aquaculture practice largely depends on the supplementary feeds provided to the system. These aquafeeds and feeding practices followed also cause some wastes which are generally ignored and not given due attention considering the profitability of the aquaculture. The environmental problems are seldom emphasised till the effects are felt. The lure of high production rates over 20 t/ha/yr at least for few years resulted in prolification of shrimp farming in many south-east Asian countries, as in Thailand and Taiwan. This continues in other countries to this day despite the much reported long-term problems in those that were the pioneers (New, 1995). Without exception, India too had to face the consequence of the much talked problem of white shrimp disease even during a short span of 2-3 years.

The major impact of feeds and feeding techniques used in intensive aquaculture consists of hypernutrification, the most important pollutant being the nutrients which normally limit primary productivity, namely inorganic phosphate and nitrogen. Though both have an impact, phosphate is generally more important in freshwaters and nitrogen in marine waters. Large amounts of nitrogen and phosphorus accumulate in the environment in the case of intensive aquaculture practices derived from aquafeeds provided to the system. For example, at a FCR of 1.5:1, salmonids utilize only 25% of the nitrogen and phosphorus in aquafeeds (De Silva and Anderson, 1995). 10% of the aquafeed phosphorus dissolves in the effluent and is immediately available for primary production. the rest 65% is particulate and released slowly. The corresponding values for nitrogen are 65% dissolved and 10% particulate forms. According to Macintosh and Phillips (1992), close to 80 and 90% of the nitrogen and phosphorus inputs of the feeds respectively are not utilized by the cultured organisms and as a result are wasted. They in turn pollute the water and accumulate at the bottom of the pond as toxic wastes. Toxic wastes stress the growing conditions and environment of the cultured organisms.

With the extensive and semi-intensive systems progressively intensified over the years, feeds designed for more intensive systems are often utilized in less intensive systems. Such feeds are formulated for conditions where little or no natural food is available and unnecessary for less intensive system resulting wastage and pollution (FAO, 1995). Further, the feeds available for shrimps are often used for fish culture ofrvice-versa, which are extremely diverse in character and their nutritional requirements. The practice is more common in case of freshwater prawn farming. At present, though the farming of freshwater prawns like *Macrobrachium rosenbergii* and *M. malcolmsonii* is gaining momentum and practised in a large scale, no specific commercial feed is available for the same. The feed provided is either restricted to ricebran-oil cake mixture or the available commercial formulation of shrimps. Similar is the case for catfish farming. In spite of the fact that they require lower protein levels than the marine shrimps, the prevalent practice of using shrimp diets containing high protein levels needs to be reviewed.

The use of single or multi-ingredient moist feeds in aquaculture has been one of the practices followed largely by most of the farmers in the country. In spite of the fact that carp culture has become an organised industry in recent days with production levels of 5-8 t/ha/yr recorded by many farmers of Andhra Pradesh and Punjab, the supplementary feed provided is limited to bran-oil cake mixture. The intensive production of carps resulting in production levels as high as 17.3 t/ha/yr, was also obtained through use of feed in the moist form (Tripathi *et al.*, 1994). Very little attention has been given to estimate level of consumption and wastage of feed supplements when provided in moist form. The experiments conducted with salmonids showed much higher levels of nutrients in the discharge when provided in wet form over dry from (Warrer-Hansen, 1992). (Table 4).

Pillay (1992) noted that the discharge from 50 t/yr marine fish farm is similar to that from the purified sewage from a community of 7000 people. Bingham (1991) reported that 45,000 t of trash fish is used in Hongkong to produce 3000 t of high value food fish in marine cages, while about 13,500 t of the trash fish pases through the cages uneaten. A survey conducted by NACA also reported large proportion of carp farms using moist formulated feeds (New, 1995). Moreover, most of the simple feed mixtures which are commonly used in many contries under carp culture are in moist form (Tables 5 & 6). Moist feeds, besides polluting environment possess the risk of disease transfer through the use of unprocessed animal ingredients. To overcome such problems, Denmark has banned the use of trash fish sine 1985 (Kiaerskolu, 1992). New *et al.* (1993) also stressed the necessity of ingredient processing and improvement of moist feed for reduction of wastage and improved efficiency. Besides the discharge of nutrients into the environments through feed, increasing use of various additives in aquafeeds is also causing concern now-a-days. The discharge of antibiotics in the effluents or their carry-over into the aquaproducts may affect disease resistance in fishes and human beings. The antibiotics usage is particularly prevalent in shrimp feeds because shrimp have a nonspecific immune system. With the increasing fears about antibiotics residues in human food, Japan, USA and Europe, the major importers of farmed shrimp have imposed strict quality definitions on south-east Asian feed stuff industry (New, 1995).

Table 4. Discharge levels in kg per tonnes of salmonids produced

	Low energy dry feed	High energy dry feed	Wet feed
Total N	60-80	25-45	180
Total P	8-10	3-5	20
Solids	300-400	150-300	600
BOD	200-300	150-250	600

Source: Warrer - Hansen (1992)

Though aquafeeds are generally blamed for causing pollution, poor feed management is also equally responsible. Feed ingredients, form of feed, proximate composition, etc. along with the feeding schedule, feed ration as also feeding style decide the profitability of the culture practices. In many cases of carp farmings feed dough is dumped into the water. Rarely the feeds are provided in trays or baskets. Feeding quantity estimation should be given more attention. In many cases, the amount of feed provided is never actually consumed by the farmed organisms. Biomass estimation at periodical intervals should also be given due attention for feeding quantity estimation.

There has already been a realization for the importance of low-pollution feeds, especially in case of salmon farming. The new salmonid feeds that have emerged depend on selecting ingredients with high phosphorus bioavailability and high digestibility, reducing the feed losses by improved water stability and balancing diets to prevent excess of certian nutrients. Reducing protein and increasing lipid levels have improved growth rates and FCR and reduced faeces and ammonia nitrogen excretion. For low-pollution diets, although protein levels are not necessarily being reduced, lipid levels are being raised to provide high energy and low FCR feeds. For example, increasing lipid levels of Atlantic salmon feeds from 22 to 30% reduced the effluent nitrogen load by 35% and phosphorus by about 20% (Johnsen and Wandsvik, 1991). Lall (1991) suggested selection of low phosphorus fish meal in feed for reduction of phosphorus discharge. The use of partially deboned fish meal was also found to reduce the phosphorus discharge significantly (Jauncey, 1995).

Unlike fish, shrimp can utilize carbohydrate to a considerably high level to spare protein, as in lipids. Though the inclusion levels of lipid in shrimp feed are unlikely to reach levels as in case of salmon, the information already available showed that the values are two to three times higher than 20 years ago (New, 1976). In most dietary studies, optimal protein requirement is over estimated. Feeding strategy as well as dietary protein quality, particularly digestibility and amino acid profile influence the quantity of nitrogen excreted (Kaushik and Cowey, 1991). Moreover, the correct protein and energy ratio for each species has become an important consideration in feed management.

Table 5. Percentage of carp farms in Asian countries feeding formulated feeds in moist form in 1995

Country	Extensive	Semi-intensive	Intensive
Bangladesh	50	87	-
China	-	6	-
India	7	34	-
R.O. Korea	-	-	4
Malaysia	3	-	-
Myanmar	-	6	-
Pakistan	33	76	-
Thailand	-	25	-
Vietnam	6	12	-

Source: Warrer - Hansen (1992)

7. Fish Quarantine

The major diseases associated with fish culture in south and south-east Asia include protozoan and microbial diseases. The protozoan diseases affect mainly fry and juveniles whereas microbial diseases affect both young and adult fishes. The most prevalent protozoan diseases of freshwater fish are caused by the holotrichus ciliates, *Ichthyophthirius*, trichodinids and myxosporidians (primarily *Myxobolus*). These protozoans are most detrimental and cause great losses of cultured fishes, be it freshwater or marine species. Many protozoans are cosmopolitan and their spread is made easier by the transportation of live fish across the national boarder which generally is done in fry or juvenile stage without quarantine (Seng, 1987). Research findings have shown that many of the fish pathogens that cause sporadic mortalities or serious epizootics were previously unknown to the region and were introduced along with exotic fish species (Shariff, 1987).

Quarantine examinations based only on visual examinations are not effective in detecting pathogens associated with fish that are leaving or entering a country. These factors have resulted in ineffectiveness of the whole exercise. Certificates issued to the exporters of fish are now merely

Table 6. Materials used as simple feeds in semi-intensive(s) and intensive (I*) carp farms using simple (non-formulated) feeds in Asian countries in 1995

Country	Bran/oil cake		Kitchen/food processing wastes		Fresh Fish/meat		Plant materials		Others	
	S	I	S	I	S	I	S	I	S	I
Bangladesh	99	-	11	-	2	1	19	-	5	-
Cambodia	100	-	58	-	1	-	84	-	88	-
China	88	11	2	-	13	-	85	100	7	22
Hong Kong	56	11	6	-	-	-	75	-	69	-
India	99	-	13	-	1	-	15	-	8	-
Indonesia	-	96	-	14	-	4	-	-	-	-
R.O.Korea	-	-	-	-	-	-	-	-	100	-
Malaysia	22	-	49	-	1	-	88	-	13	-
Myanmar	100	-	-	-	-	-	1	-	-	-
Nepal	94	-	11	-	3	-	9	-	11	100
Pakisthan	75	-	25	-	1	-	23	-	25	-
Thailand	79	-	40	-	5	-	51	-	8	-
Vietnam	90	71	21	7	19	-	85	86	9	7
Philippines	-	50	-	-	-	-	-	-	-	50

* Extensive and semi-intensive are ponds; intensive are pens and cages.

Source: New (1995)

looked upon as a permit or license of export rather than as a document of declaration that fish meant for export are actually free of disease causing agents.

Legislation for quarantine and certification procedures does not exist as yet in our country. Upon arrival, the fish are released immediately to the importer. No holding or disease screening procedures are undertaken at present. Steps are being taken for the formulation of quarantine and certification procedures and it is proposed that Central Institute of Freshwater Aquaculture, Bhubaneswar would be assigned to co-ordinate the quarantine activities of the country with centres located at different regions or points of import.

8. Integrated Fish Farming

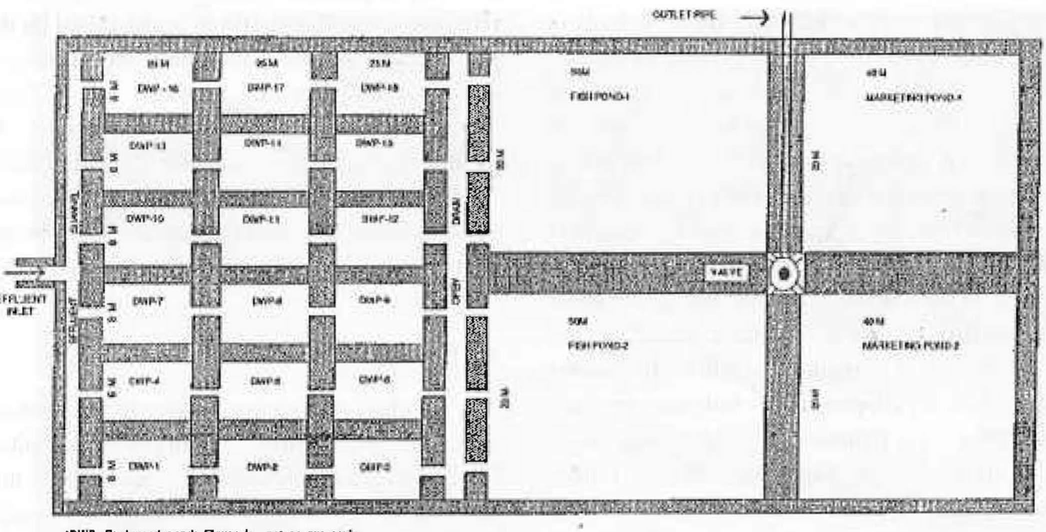
Intensification of fish farming practices is bound to produce adverse impact if not optimised with reference to inputs. Continued application of inputs like fertilisers and feed, not properly utilized in the pond system leads to eutrophication, resulting in oxygen depletion, increase in NH_4 level and ultimately the disease outbreak.

Integrated fish farming on the other hand efficiently recycles all the wastes from the animals, agricultural crops and related processing industries, resulting ultimately in protein-rich food at considerably low investments. It comprises various models in fish-livestock-crop farming activities, the combinations being biologically harmonious, quantitatively optimal and economically feasible as approved, fish-crop, fish-livestock and fish-processing systems, etc. make use of the left overs of the wastes which have feed and fertilizers value. With integrated fish farming considered to be an economically profitable, technologically sound and environmentally congenial farming practice, it is necessary to maintain the inputs at optimal levels for sustainability without adverse impacts. While the aquatic environments can process a large amount of wastes, their continuous application results in silting up of pond basins and anaerobic conditions. In order to achieve a good production, supplementary feeds are provided over and above the application of organic input which in turn leads to greater accumulation of pond mud year after year. This leads to serious outbreak of fish diseases and oxygen depletion, and threaten the fish life. Examples of such incidence in Zhejiang province of China had resulted in a fish loss of over 500 tonnes from about 500 ha area during 1989 due to disease incidence, while in 1990 in Wuxi, Jhiangsu province, oxygen depletion resulted in fish death causing 30% loss of the total farming areas including those species which have high environmental tolerance as common carp, crucian carp and other bottom dwellers (Kuanhong, 1995).

Integrated fish farming however provides for recycling of organic wastes, both plant and animal-based and could be a potential tool for waste recycling. In this context, the design of a wastewater treatment system by CIFA at Cuttack, Orissa using a series of duckweed and fish pond provides for waste utilization and treatment of domestic sewage (Fig. 1, 2 and 3). The sewage-fed fish culture, having a long tradition in the country actually provides for positive environmental impact of the aquaculture systems. Organic farming comprising recycling of domestic sewage, processed plant and animal residues, etc. has been the recent trend, highly suitable for an agrarian economy like India, providing for sustainability in aquaculture as also environmental upkeep.

9. Water Budgeting

The country receives an annual rainfall of about 400 million hectare metre (mhm) water, of which 230 mhm goes back into the atmosphere through evapotranspiration. The remaining 170 mhm is carried into the sea by the rivers every year, much of it (110 mhm) during rainy season and rest after percolation to underground and subsequent emergence into streams. Further, the ground water



*DWP: Duckweed pond; Figure is not as per scale

Fig. 1. Plan of aquaculture treatment system for domestic sewage at Matagajpur, Cuttack, Orrisa, India

upto 300 m contains 3,700 mhm, about 10 times the annual rainfall (Parameswaran, 1995).

Theoretically, a large quantum of 170 mhm water is available in India for irrigation and other uses, which is estimated to be enough to meet the entire irrigation needs of the country. However, irrigation systems of 40 mhm (30 mhm canal water + 10 mhm well water) only has been developed so far, which irrigate only 25% of the aerable land while the streams carry rest 130 mhm annually. Further, considering various limitations, it is estimated that it is not possible to harness more than 70-80 mhm water.

One of the important items in freshwater aquaculture is the water requirement, either in hatcheries or in grow-out systems, the information on the quantitative aspects being however lacking. Several states treat aquaculture as an industry as in Maharashtra and charge exhorbitantly for water from reservoirs, while other treat it as an agricultural activity. Even where the irrigation water is given for aquaculture, it is only the surplus and extra water after meeting the needs of agriculture, industries, etc. The left-over water is the only one over which aquaculture can claim (Dehadrai, 1995). It is estimated that freshwater aquaculture at present is utilizing 9.5 billion m^3 water under the existing 0.745 million ha pond area, which is expected to increase to 36.2 billion m^3 at the complete development of the remaining 1.755 million ha of existing water bodies and additional creation of 25% of them as new ponds *i.e.* 0.439 million ha. thus, considering the water availability of 70-80 mhm, a share of 5% (3.6 mhm) must be made available for freshwater aquaculture, by adopting parity and equity between agriculture and fisheries especially aquaculture and allotment of water as national policy guidelines. Further, scientific studies have established that irrigation water could be nutritionally enriched if it passess through fish farms. The conjuctive use of water for agriculture and aquaculture in possible by passing irrigation canal water through aquafarms to fields. Thus the quantity of water required for water exchange in aquaculture is not considered as additional water demand from the country's water source, other than the evaporation and seepage losses.

10. Depuration of Fish Cultured in Waste Water

Indian sewage-fed fisheries started in West Bengal around 1925, which presently is being practised over an area of about 4000 ha. Earlier waste water was arbitrarily used in fish culture without taking into consideration the health aspects, but gradually precautionary measures are being incorporated with regard to health and hygiene. There are potential threats to public health from the fish raised in wastewaters and the degree of risk varies considerably with the types of pathogens concerned. There is little danger of disease from eating of well-cooked fish since the heat destroys pathogens, but the consumption of raw, partially cooked or improper preserved products can be a serious health hazard, generally overlooked. It is generally believed that fish carry human pathogens passively only in their intestines and in their body surface. Prior waste treatment pathogen destruction is being suggested. Further, it is essential to eliminate the potential risk to health posed by the presence of several pathogenic faecal micro-organism in fish reared in waste water. Thus, certain measures need to be undertaken, as depuration of fish in clean water ponds before final harvesting. The normal depuration measure consists of holding the fish cultured in sewage waters for a period of 48-72 hours before marketing the produce.

11. Energy Inputs

The viability of any farming system depends on the economy of returns, in terms of land, capital, labour and entrepreneurship. In recent years, this aspect is being evaluated in terms of total energy inputs-environmental, manual and mechanical. Some farming systems are even being threatened due to high energy demands in terms of manual labour, in which context, mechanisation is assuming increasing importance. Attempts have

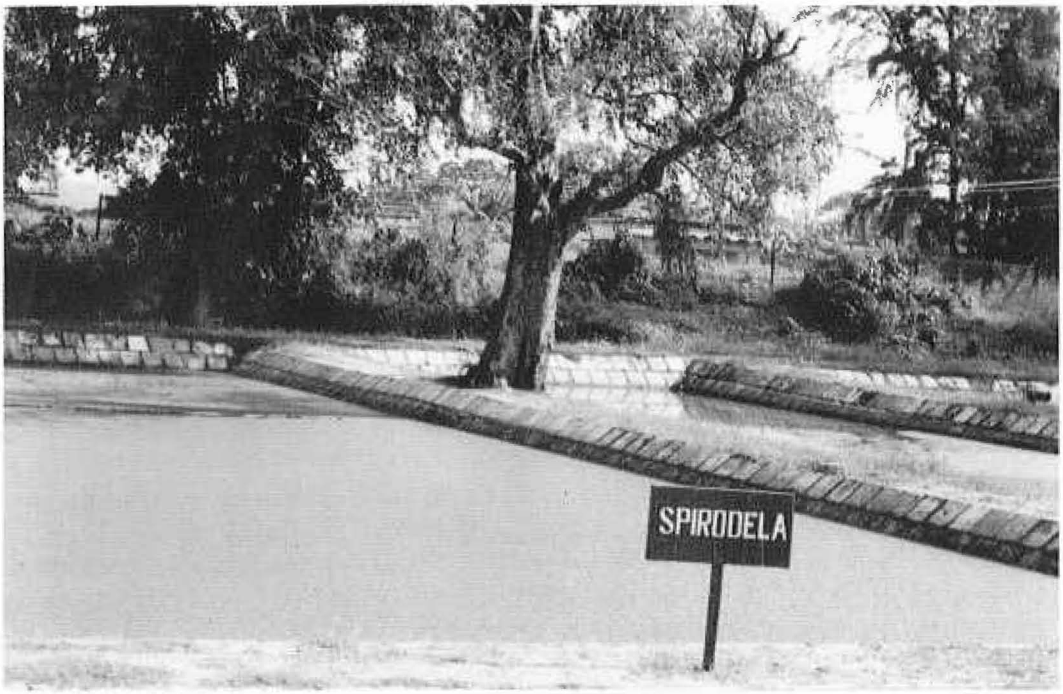


Fig. 2. Duckweed

Fig. 3. Treatment of domestic sewage

been made to quantify the energy inputs and evolve the energy budgets for plant and animal-based farming systems. Such an exercise is totally lacking in freshwater aquaculture and efforts are presently underway at preparation of energy budget models for different freshwater aquaculture systems.

12. Fish Marketing and Hygiene

With most fish, both marine and freshwater included, marketed fresh in the country very little post-harvest processing is carried out. Even the meagre processing of marine fish is confined to drying, salting, etc. though icing is a common practice for short distance transport. With a boom in freshwater aquaculture, this aspect is receiving greater attention in recent years.

Improper fish handling including transport of fish in baskets and containers that are repeatedly used is a source of contamination. Ice used for temporary preservation often is a source of contamination of human pathogens. The absence of a cold chain with hygienic selling places is of major concern and an environmental issue in fish marketing. Aquaculture planning needs to consider not only the development of facilities for culture *per se,* but also the post-harvest preservation and marketing measures. Necessary quality standards have to be evolved and enforced as in the case of processing and export of marine produce.

13. Environmental Modification and Recovery

Biopurification of sewage wastes employing aquatic vegetation has been found to be an effective and environment-friendly means to combat the pollution hazards. Bryopohytes, mosses with their delicate and uncuticularised plant body have a marked capacity for absorbing and accumulating pollutants. Some aquatic plants that grow well in wastewaters like *Eichhornia, Wolffia, Lemna, Spirodela, Hydrilla, Ceratopohylum, Phragmites, Scirpus* and *Typha* absorb considerable amount of nutrients and heavy metals, as also reduce the BOD levels. It has been calculated that 20-40 tonnes of *Eichhornia* is capable of removing the nitrogenous waste of over 1000 people and phosphorus waste of over 800 people (Jhingran, 1991). Biofertilizers, processed organic material and biofilters are some of the inputs with high application potentials in aquaculture systems, providing for environmental modifications as also products that could be substituted for chemical inputs or mechanical devices.

Processed organic input in aquaculture

With a dominance of organic inputs in freshwater fish culture, cattle dung and poultry droppings are the two major animal excreta used for the purpose. As a large fraction of the organic matter applied in the ponds has been observed to remain unutilized with associated environmental problems, the advantages of processing the organic matter prior to application are being considered. They incldue higher mineralisation and nutrient release rates, reduced in-pond oxygen demand for manure processing, marginal increase in the nitrogen content of the substrate due to microbial processing, low siltation rates, etc. (Ayyappan, 1994). Apart from cowdung that is traditionally used, several organic inputs like animal excreta, straw, green fodder, water hyacinth, etc. have been used as inputs in biogas plants. Further, the saving in fertilization practices with biogas slurry over the recommended manurial schedule in carp culture amount to 13.3 - 40.5%. This assumes significance in view of the increasing costs and scarcity of inorganic fertilizers, as also associated environmental impacts of long term use of inorganic fertilizers. Besides these, the biogas plant suitably process and recycle several natural organic resources like aquatic macrophytes and agricultural byproducts that are otherwise wasted.

Azolla - A new biofertilizer

Azolla, a free floating aquatic fern fixing atmospheric nitrogen through the cyanobacterium, *Anabaena azollae,* present in its dorsal leaves, is one of the potential nitrogenous biofertilizers. Its high nitrogen-fixing capacity, rapid multiplication and decomposition rates resulting in quick nutrient release rates have made it an ideal biofertilizer for farming systems. The normal, doubling time of *Azolla* is three days and one kilogram of phosphorus applied results in 4-5 kilogram of nitrogen through *Azolla i.e.* about 1.5 - 2.8 tonnes of fresh biomass. For fertilizing 1 ha of water area at the rate of 40 t/ha/yr (providing 100 kg nitrogen, 25 kg phosphorus, 90 kg potassium and 1500 kg organic matter) as a total substitution for the traditional organic manures and inorganic fertilizers recommended in carp polyculture, about 550 m^2 water spread area is required (1.5 kg/m^2/week, 42 t/yr), with total area of 800 m^2, accounting for 8% of the area to be fertilized (Ayyappan *et al.*, 1993). While *Azolla* is useful in aquaculture practices primarily as a nitrogenous biofertilizer, its high rates of decomposition also make it a suitable substrate for enriching the detritus food chain or for microbial processing such as composting prior to application in ponds. It can also serve as an ingredient of supplementary feeds and as forage for grass carp. A saving to the extent of 48.5% over the recommended manuring schedule is estimated through *Azolla* biofertilization (Ayyappan, 1994).

Waste utilization

Biological treatment of wastewater, already occurring in nature, but standardised with introduction of specific microbial inoculants or scaled-up designs is a potential area compatible with freshwater aquaculture. The objectives of using sewage for fish culture are two folds: utilization of nutrients in wastewater for fish production being the earlier concept, and using aquaculture as a tool for treatment of sewage and wastewaters being the recent trend. Further, the aspect of reduction of nutrient and bacterial loads through fish culture has been considered and shown effective with regard to counts of total and faecal coliforms, faecal streptococci and *Salmonella*. Fish culture not only reduces the nutrient load in the waters, but also causes a reduction in bacterial load, as evidenced by the works in a Nigerian sewage-fed fish culture systems. The reduction rates in the bacterial populations from the influent to the effluent during a retention time of 12 days were total viable counts 4.5 x 10^9 to 1.7 x 10^6/ml, total coliform counts 2.7 x 10^7 to 2.7 x 10^5/ml, faecal coliforms 4.5 x 10^6 to 1.3 x 10^4/100 ml, faecal streptococci 1.4 x 10^4 to 3.3 x 10^2/100 ml and *Salmonella* 2.7 x 10^2 to 1.2 x 10^2/100 ml. The reduction might have been brought about by a combination of natural inactivation processes, adsorption to sediments and uptake by fish. It may be emphasised that all these culture systems are independently economically viable units and as such would provide considerable returns (Ogbondeminu and Okoye, 1992).

Distillery effluents are also a major resource in the country with about 150 distilleries producing 900 million litres of alcohol annually resulting in 10,000 million litres of spent wash. The efficacy of aquaculture as a tool for treatment of such wastes has been demonstrated at Madras, where the effluent after undergoing the biomethanation process, is fed into fish ponds. With production rates of 50 t/ha/yr, about 6 ha of land area has been shown to be adequate for treating 100m^3 of effluents. This has opened avenues for utilising a variety of agro-based industrial effluents as also for treating them through aquaculture practices, largely based on microbial processes, in terms of oxidation or nutrient removal through algae and other macrophytes.

In terms of solid wastes also, the resource in the country is huge in terms of agro-residues amounting to 321 million metric tonnes per year (Ramachandran and Sinha, 1993). As already mentioned, on bioconversion of these lignocellulosic wastes, they can be applied to fish ponds as manure/feed which process also results in usable products like single cell protein and biogas.

14. Epilogue

With environmental issues being discussed with reference to any developmental activities, agricultural or industrial, it is relevant and essential that the freshwater aquaculture related environmental issues are also analysed for formulating guidelines for the development of the sector. Unlike other areas where these issues were take-up often as a post-mortem, they have been discussed even when the sector has not caused serious problems. With intensification of culture practices being the trend in recent years, issues as listed have been foreseen and remedial measures implemented properly would pave way for not only increasing productivity but also sustainable aquaculture. Farming systems approach providing for utilisaltion of wastes from one culture system as an input or resource for another system, with proper designs is being discussed for sustainable agricultural practices including freshwater aquaculture.

References

Anon, 1995. Fishing Chimes, 15(8) : 56.

Ayyappan, S., 1994. Environmental managemnt for increased aquatic productivity. pp. 233-252. *Symp. Env. Biotech.*, 28-29 March 1994, NEERI, Nagpur, India

Ayyappan, S., Dash B., Pani, K.C. and Tripathi, S.D., 1993. *Azolla*-a new aquaculture input. National. Meet on *Aquafarming Systems - Practices and Potentials*, 10-11 Feb 1993, Bhubaneswar, OFS-3.

Bandyopadhyay, B. P., 1995. Aquatic pollution with special reference to the effect of pesticides and insecticides on fish and fisheries. *Fishing Chimes*, 15(3): 27-30.

Bhatnagar, S. P. 1995. Rajasthan News letter, *Fishing Chimes*, 15(8): 56-58.

Bingham, A., 1991. The deeper the better. Far Eastern Economic Review, October 1991: 27-28.

Chottoraj, A. N., 1987. Some aspects of biological interaction of insecticides. *Proc. Indian Science Cong.* Abstract, 3: 1-7.

Dehadrai, P. V., 1995. Water requirements for fisheries in India: A scientists perspective.

De Silva, S. S. and Anderson T. A., 1995. Fish nutrition in aquaculture. Chapman and Hall, London, England, 319 pp.

Dutta, H. M., Dogra, J. V. V., Singh, N. K., Roy P. K., Nasar, S. S. T., Adhikari, S., Munshi J. S. D. and Richmonds, C., 1992. Malathion induced changes in the serum proteins and haematological parameters of an Indian catfish, *Heteropneustes fossilis* (Bloch). *Bull. Environ. Contam. Toxico.*, 49(1): 91-97.

FAO, 1995. Review of the state of world fishery resources: aquaculture. FAO *Fisheries Circular*, 886: 127 pp.

Gupta, G. P., 1975. Sediment production status report on data collection and utilization. *Soil Cons. Diges.*, 3(2): 10-21.

Jauncey, K., 1995. Advances in freshwater fish nutrition. 28 pp. Proceedings of VICTAM 95 Symposium "From Feed to Food" 17-18 May 1995, Utrecht, Netherlands. Victam International, Leiden, Netherlands.

Jhingran, A. G., 1989. Role of exotic fishes in capture fisheries waters of India. *In:* A. G. Jhingran and V. V. Sugunan (Eds). Conservation and management of inland capture fisheries resources of India. Inland Fisheries Society of India, CIFRI, Barackpore, 275 pp.

Jhingran, A. G., 1991. Impact of environmental stress on freshwater fisheries resources. *J. Inland Fish. Soc. India*, 23(2): 20-32.

Johal, M. S. and Tandon K. K., 1983. The decline of native fishes. *Punjab Fisheries Bull.*, 9(11): 3-15.

Johnsen, F. and Wandsvik A., 1991. The impact of high energy diets on pollution control in fish farming industry. pp. 51-63. *In:* C. B.

Cowey and C. Y. Cho (Eds). Nutritional strategies and aquaculture waste. University of Guelph, Ontario, Canada.

Kaushik, S. J. and Cowey C. B., 1991. Dietary factors affecting nitrogen excretion by fish. pp. 3-19. In: C. B. Cowey and C. Y. Cho (Eds.). Nutritional strategies and aquaculture waste. University of Guelph, Ontario, Canada.

Kiaerskou, J., 1991. Production and economics of low pollution diets for the aquaculture industry, pp. 65-76. In: C. B. Cowey and C. Y. Cho (Eds). Nutritional strategies and aquaculture waste. University of Guelph, Ontario, Canada.

Kuonhong, M., 1995. A few factors related to sustainable management in integrated fish-livestock-crop farming. *ADB/NACA Workshop on Aquaculture Sustainability and the Environment,* 6-12 October, 1995, Beijing, China.

Lall, S. P., 1991. Digestibility, metabolism and excretion of dietary phosphours in fish, pp. 21-36. *In:* C. B. Cowey and C. Y. Cho (Eds). Nutritional strategies and aquaculture waste. University of Guelph, Ontario, Canada.

Macintosh, D. J. and Phillips M. J., 1992. Environmental Consideration in shrimp farming. INFOFISH International, 6/92: 38-42.

Mahanata, P. C., Kapoor D., Dayal R. and Ponniah A.G., 1994. Prioritization of the Indian fish species for conservation. pp. 379-385. *In:* P. V. Dehadrai, P. Das and S. R. Verma (Eds.). Threatened fishes of India. Proceedings of the National Seminar on Endangered Fishes of India, National Bureau of Fish Genetic Resources, Allahabad, India.

Najmi, T. A., Sharma, V. and Khan, A. H., 1992. Toxic effects of endosulfan on the stomach of *Clarias batrachus* (Linn). *Indian J. Pure Appl. Bio.*, 7(1): 47-51.

New, M. B., 1976. A review of dietary studies with shrimp and prawns. *Aquaculture,* 9: 101-144.

New M. B., 1995. Feed management and nutrition of sustainable aquaculture. *ADB/NACA Workshop on Aquaculture Sustainability and the Environment,* 6-12 October, 1995. Beijing, China.

New, M. B., Tacon, A. G. J. and Csavas I., 1993. Farm-mdae aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14-18 December, 1992. FAO/RAPA, Bangkok, Thailand.

Odum, E. P., 1971. Fundamentals of ecology. W. B. Saunders Co., 574 pp.

Ogbondeminu, F. S. and Okoye, F. C., 1992. Microbial evaluation of an untreated domestic waste water aquaculture system. *J. Aqua.* Trop., 7: 27-34.

Pandey, A. K. and Bhattacharya L., 1990. A differential scenario of five insecticides exposed to *Oreochromis mossambicus,* maturing and matured ova. *Second Indian Fish. Forum,* Mangalore, India, 276 pp.

Parameswaran, S., 1995. Toxic wastes - a potential danger to freshwater fisheries and aquaculture resources. *Fishing Chimes,* 14(10): 63-68;

Rao, M. B., 1995. The environmental impact of chemical inputs in open aquaculture systems - a perspective. *Fisheries Fortune,* Souvenir, 22 pp.

Ramachandran, S. and Sinha S., 1993. Bioconversions. *Indian. J. Microbiol.,* 33(1): 25-34.

Rudd, R. L., 1964. Pesticides and living landscape.

Univ. of Wisconsin Press, Marson, 320 pp.

Sharma, A., 1987. Resources and human welbeing. 74th *Session Indian Science Congress Association,* Bangalore, pp. 32.

Shariff, M., 1987. Current status of programs for fish health certification and quarantine system. *In:* J. R. Arthur (Ed.). Fish Quarantine and Fish Diseases in South and Southeast Asia: 1986 update. *Asian Fish. Soc. Spec. Publ.* 1, 86 p. Asian Fisheries Society, Manila, Philippines.

Sreenivasan, A., 1996. Why exotic species ? *Fishing Chimes,* 16(1): 9-10.

Sukumar, A. and Karpagagnapathy P. R., 1992. Pesticides induced atresia in ovary of a freshwater fish, *Colisa lalia* (Hamilton - Buchanan). *Bull. Environ. Contam. Toxico.,* 48(3): 457-462.

Tak-Seng, Leong, 1987. Recent fish disease problems in south and southeast Asia and their economic impacts. *In:* J. R. Arthur (Ed.). Fish Quarantine and Fish Diseases in South and Southeast Asia: 1986 update. *Asian Fish. Soc. Spc. Publ.* 1, 86 p. Asian Fisheries Society, Manila, Philippines.

Tripathi, S. D., Aravindakshan, P. K., Ayyappan, S., Jena, J.K., Muduli, H. K., Suresh Chandra and Pani, K. C., 1994. A new high in carp polyculture: 15 tonnes per ha per year. *Nat. Symp. Aquacrops,* 16-18 November, 1994. Indian Fisheries Association, CIFE, Bombay.

Warrer - Hansen, I., 1992. The right treatment for wastewater. *Fish Farming International,* 19(8): 36-37.

Woodwell, G. M., Wurster, C.F. and Isacson, P. A., 1967. DDT residuces in an east coast estuary: a case of biological concentration of a persistent insecticide. Science, 156: 821-824.

3

Packages of Practices for Sustainable, Ecofriendly Mariculture (Land-based Saline Aquaculture and Seafarming)

M. Devaraj, V.K. Pillai, K.K. Appukuttan, C. Suseelan, V.S.R. Murty, P. Kaladharan, G. Sudhakara Rao, N.G.K. Pillai, N.N. Pillai, K. Balan, V. Chandrika, K.C. George and K.S. Sobhana

Central Marine Fisheries Research Institute, Cochin-14

1. Introduction

The problems of fast growing human population and protein deficit, particularly in the developing countries, continue to exert pressure on the fisheries resources available for exploitation in the wild waterbodies. The increasingly limited opportunities in the capture fisheries sector have generated considerable interest in aquaculture. The potential of aquaculture in meeting the increasing demands for fishery products, generating income and profits and contributing to sustainable food supplies is considered to be quite significant.

A recent report of the Consultative Group on International Agricultural Research stated that within the next 15 years, fish farming and searanching might provide nearly 40% of all fish for the human diet and more than half of the value of the global fish catch. According to a report of the FAO, the world aquaculture production is likely to increase by 2.69 times by 2025, growing from 19.3 million tonnes in 1992 to 26.9 million tonnes in 2000 and to 51.8 million tonnes in 2025. Marine finfish production by farming is expected

AQUACULTURE AND THE ENVIRONMENT
ISBN 81-85340-17-X

to increase from 0.36 to 1.0 million tonnes, molluscs from 3.5 million tonnes to 8.9 million tonnes and seaweeds from 5.4 million tonnes to 9.8 million tonnes from 1992 to 2025. In India the 1995 production from coastal mariculture (mostly extensive to semiintensive systems of shrimp farming) was reported to be around 85,000 tonnes from an area of 0.12 million ha. The total mariculture production including shrimps, bivalves and finfishes is expected to increase to 2 million tonnes by the year 2025.

There is vast scope for the development of aquaculture in many areas, particularly in the tropics. However, the development of aquaculture is being increasingly subject to a wide range of environmental, resource and market constraints and scrutiny. The interaction of aquaculture with the environment may result in significant ecological changes. The expansion of aquaculture in recent years has led to substantial socioeconomic benefits. It is generally held that the majority of aquaculture practices have had little adverse effect on the ecosystems. Nevertheless, some cases of environmental changes in coastal areas have occurred due to, for example, intensive cage culture operations in Europe and shrimp farming practices in Southeast Asia, Latin America and the east coast of India. Aquaculture is competing for land and water resources and, in some cases, comes into conflicts with other resource users. There is growing concern about the effects of aquaculture operations and various types of industrial, domestic and agricultural pollution on the environment. In several cases, environmental problems have resulted from conversion of wetland habitats, nutrient and organic waste discharges, introduction of exotic species, chemical usage, and from the deterioration of water quality and increasing acquisition of suitable sites by the corporate sector for aquaculture.

The experiences gained from these issues have emphasised the urgent need for the development of sustainable aquaculture with due ecological considerations. It is now widely experienced and believed that diversification of the species base of mariculture production systems (growouts) in polyculture through a careful choice of species, compatible among themselves, would minimise the ill effects of monoculture systems.

2. Fish Supply and Demand

The proportion of fish eating people in India increased from 27.7% in 1987-88 to 39.7% in 1996-97. Assuming that this proportion would increase at least to 50%, the total fish eating population in India by 2020 will be around 650 million. Considering the optimum per capita nutritional requirement of fish of 11 kg/year, the total quantity of fish required for domestic consumption by 2020 will be around 7.2 million tonnes of which (at the present ratio of 2.7 million tonnes of marine fish production to 2.1 million tonnes of inland fish production i.e., 56.2% marine and 43.8% freshwater), 4.1 million tonnes of fish has to be realised from the marine fisheries sector and 3.1 million tonnes from freshwater capture fisheries and aquaculture. The projected marine products exports by 2020 A.D. is 0.9 million tonnes, and hence, the total marine fish production by 2020 A.D. has to be increased to 5 million tonnes. The current total marine fish production from the capture fisheries sector (2.7 million tonnes) and the coastal shrimp aquaculture sector (0.08 million tonnes) is 2.78 million tonnes.

Table 1. Marine fish production requirements of India by 2020 A.D.

I. Fishery resource potential		
Marine :	3.9 million t	
Inland :	4.5 million t	
Total	8.4 million t	
II. Fish production 1994-95 (Figures of Ministry of Agriculture)		
Marine :	2.69 million t (56.2%)	
Inland :	2.10 million t (43.8%)	
Total	4.79 million t	
III. Human population and fish requirement		
a. Expected human population by 2020 A.D.		1300 million
b. Expected fish eating population by 2020		650 million
c. Per capita nutritional requirement of fish		11 kg/yr
d. Estimated requirement of fish for domestic consumption by 2020		7.2 m.t.
IV. Marine fish production requirement		
a. Marine fish production required by 2020 for domestic consumption (56.2% of 7.2 million t)		4.1 m.t
b. Marine fish production required for export by 2020		0.9 m.t
c. Present export		0.3 m.t
d. Total requirement by 2020		5.0 m.t
e. Present production by capture		2.7 m.t
f. Present production by culture		0.08 m.t
g. Total		2.78 m.t
h. Additional quantity required		2.22 m.t
V. Sources of marine fish by 2020 for domestic and export markets		
a. By continuing the current annual yield (Capture: 2.7; Culture: 0.08)		2.78 m.t
b. From future capture fisheries beyond the 50 m depth (total from capture fisheries: 2.7 + 0.6 = 3.3 x 106t)		0.60 m.t
c. From future mariculture (80% shrimps, 10% bivalves & 10% finfishes)		1.62 m.t
Total		5.00 m.t

This assessment shows that the country has to produce an additional 2.22 million tonnes of marine fish (over and above the present production of about 2.78 million tonnes) to meet the domestic (4.1 m.t) and export (0.9 m.t) requirements by 2020. However, the additional scope from the marine fisheries sector is only to the extent of another 0.6 million tonnes; i.e., a total of about 3.3 million tonnes although the estimated EEZ potential is about 4 million tonnes. Mariculture in coastal shrimp farms is expected to produce about 1.7 million tonnes including 80% shrimps, 10% bivalves and 10% finfishes (Table 1). However, the total seaweed culture potential alone is estimated to be over 4 million tonnes, which could be achieved in phases of, say, 2 million tonnes by 2020, i.e., 25% of the global estimated production of about 10 million tonnes by 2020 (Table 2). Besides, low saline soil water sheds of about 8.5 million ha also offer good scope of saline aquaculture (Table 3).

It is possible that any shortfall in the production from marine capture fisheries or mariculture would be offset by commensurate production from the freshwater sector. As against the projected production of 3.1 million tonnes of fish from freshwater capture fisheries and aquaculture by 2020, the production potential of this sector is estimated to be 4.5 million tonnes.

Table 2. Aquaculture potential of seaweeds in India by 2020 AD

Resource (in tonnes)	Period 2000	2005	2010	2015	2020
Agarophytes	80,000	3,35,000	5,96,000	6,50,000	7,00,000
Alginophytes	20,000	90,000	1,20,000	1,60,000	2,00,000
Carrageenophytes	40,000	2,85,000	5,04,000	6,50,000	7,00,000
Edible & Green Seaweeds	60,000	90,000	1,80,000	3,40,000	4,00,000
Total	2,00,000	8,00,000	14,00,000	18,00,000	20,00,000

(Maximum potential : 4 million tonnes)

Table 3. Mariculture potential in India (land-based saline aquaculture and seafarming)

Sl. No		T.A.(ha) Million	P.C.A.(ha) Million	C.C.A.(ha) Million	C.A.P. Tonne
1.	Coastal land based	2.5	1.2	0.12 (shrimps)	85000
2.	Hinterland saline soil aquiferbased	8.5	–	100 ha (Haryana) mullets, pearlspot, shrimp & giant prawn)	200 (milkfish,
3.	Seafarming				
i)	Actual seafarming				
a)	Open sea (EEZ)	202	1.8 (Inshore 0 to 50m depth)	2 ha (during 1996)	15 (mussel)
b)	Bays, coves & gulfs		10700 ha	Nil	Nil
c)	Mainland brackishwater lakes & estuarine mouths (Chilka, Pulicat, Ashtamudi, Vembanad etc)		2050 ha &PVT)	5ha (CMFRI oyster; 1996)	60 (edible during
d)	Inland lagoons & lakes		35000 ha	Nil	Nil
ii)	Stock enhancement programme				
a)	Searanching	18 (inshore 0 to 50m depth)	18 (inshore)	Nominal (shrimp, pearl oyster, clams and seacucumber)	Nominal
b)	Artificial fish habitat:				
	Bottom artificial reefs		1.8 (10% of inshore)	50 Reefs	10 t during Nov. to Mar. (12% of total)
	Floating fish aggregating devices		1.8 (10% of inshore)	150 FADs	

T.A. = Total area; P.C.A. = Potential cultivable area;
C.C.A. = Current cultivated area; C.A.P. = Current annual production

3. Current Marine Fisheries Problems and Solutions

Marine fisheries in India are characterised by the problems of stagnation in capture fisheries production and too many hurdles to coastal shrimp aquaculture during the current decade. Environmental and socioeconomic management of coastal aquaculture through the processes of diversification of shrimp aquaculture and seafarming is a challenging task. Coastal aquaculture and seafarming are very diverse in terms of the people involved, the resources used, the farming practices followed, and the environmental characteristics of the existing and potential sites. There are, however, opportunities for greater expansion, adaptation and integration in the onshore saline aquaculture sector (in inland saline ecosystem and coastal land ecosystem) and seafarming practices within the total mariculture development process. This could be achieved by progressively:

a. Expanding and diversifying coastal shrimp aquaculture to include other compatible candidate species.

b. Expanding inland saline aquaculture from the present experimental activities in Hariyana to all the States in phases (the total hinterland saline area is about 8.5 million ha)

c. Seeking to integrate small scale seafarming with the seafishing practices

d. Undertaking marine fisheries habitat enhancement through the construction of artificial reefs (AF's) and fish aggregating devices (FAD's) and searanching of premium stocks like shrimps, lobsters, crabs, groupers, mussels, pearl oysters etc, for the benefit of the coastal and hinterland communities and the industry (Table 3)

The implementation of these programmes would make it necessary to consider allocation of exclusive fishing and farming sites to the users over their respective areas of operation and also the protection of the standing stocks against the polluting effects of chemical-based industries.

4. Status of Coastal Shrimp Aquaculture

Coastal shrimp hatcheries and growouts have come up all along the Indian coast (Figs 1 to 4). Cultured shrimp (penaeids) production increased steadily from 1990-91 to the peak of about 90,000 tonnes during 1992-93 but declined to the current (1995- 96) 70,573 tonnes from an area of 0.12 million ha due to problems of diseases which struck the hatcheries and farms in the late 1994. With better farming practices, the production during 1996- 97 is expected to cross 100,000 tonnes. The current shrimp aquaculture situation could be characterised as follows:

a) Unfounded fears about the growth of shrimp farms along the Indian coast, and unnecessary hurdles to their sustained growth

b) Inadequate handling of the farm effluents till late 1994, but proper treatment and use subsequently

c) Extensive to improved extensive system of farming by small farmers (<5 ha) is predominant (over 80%) while semiintensive to intensive system of farming by big farmers is carried out in only less than 20% of the cultivated area.

d) Clandestine import of shrimp seedlings from some Southeast Asian countries during 1992-93 due to heavy seed deficit, paving the way for the establishment of over 170 hatcheries with 8 billion seed capacity (Fig. 4).

e) Occasional substandard consignments of imported feeds resulting in environmental and disease problems, and a serious, but temporary setback to the industry, especially along the east coast; establishment of CP feed mill at Red Hills, Madras (Chennai) and Higashimaru feed mill at Shertala, Cochin (Kochi) has reduced the need for import of feeds.

The problems outlined above are now being managed by the industry (small as well as large farms) through the adoption of:

a) Closed systems of farming in the growout farms involving the application of benovolent bacterial products.

b) Secondary aquaculture practices in the reservoirs, drain canals and bioponds.

c) Indigenisation of seed and feed production in commercial terms. The candidate species now being sought after for secondary aquaculture include the seabass,grey mullets, milkfish, groupers, breams, red snappers, seacucumbers, pearl oyster, clams, edible oysters, mussels and seaweeds.

Seed production technology for the commercial shrimp species such as *P. indicus, P. monodon, P. semisulcatus, P. merguiensis and P. japonicus* were developed way back in 1985 at the Narakkal (Kochi) Field Mariculture Centre of the CMFRI. Based on this technology one hatchery at Mopla Bay (Kerala) for P. indicus (10 million capacity) was established and commissioned during

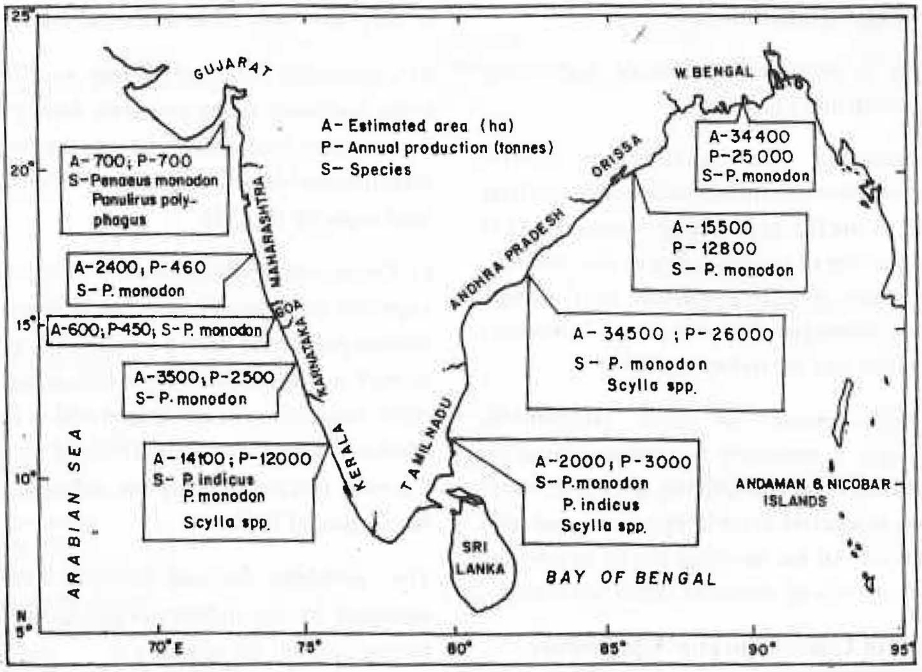
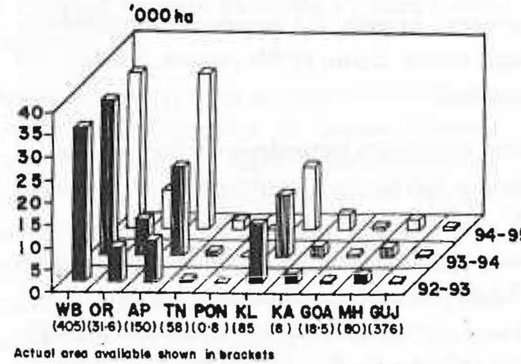


Fig. 1. Cultivated areas and annual production of crustaceans in different maritime states of India (1994-95)



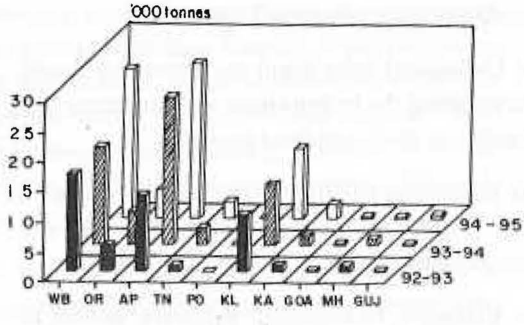


Fig. 2. Area currently under shrimp farming in different states

Fig. 3. Culturaled shrimp production in different states

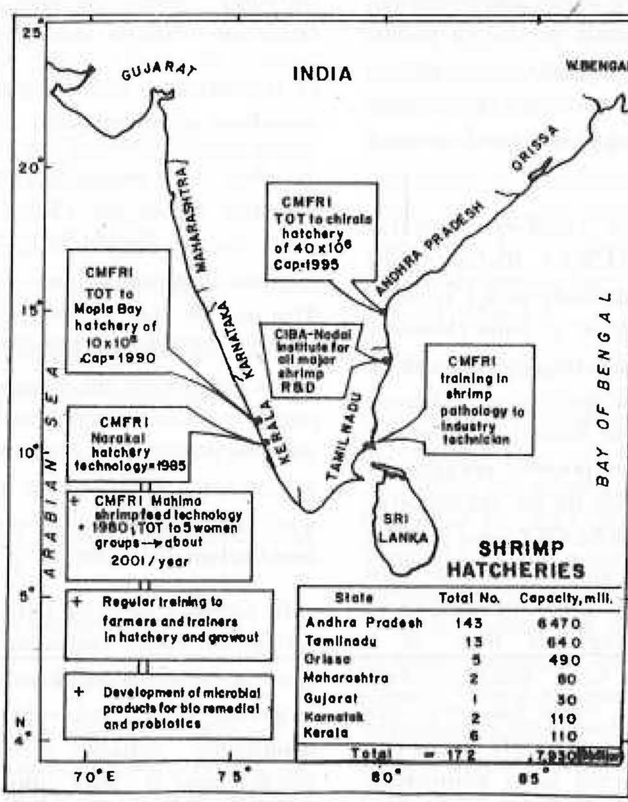


Fig. 4. Shrimp hatcheries and CMFRI's contributions

January-March, 1990. Another shrimp hatchery for *P. monodon* (40 million capacity) had been established at Chirala, Andhra Pradesh under CMFRI consultancy. This hatchery was commissioned in March 1995 and 5.2 million seed (PL 20) was produced in three runs (Fig.4). However, it was only with the establishment of two public sector commercial hatcheries, one each in Andhra Pradesh and Orissa by the Marine Products Export Development Authority using imported technologies, private sector hatcheries began to be established on a large scale.

Most of the formulated feeds used in India are imported ones and cost above Rs. 60/kg, which is beyond the reach of the small farmers. The Mahima shrimp feed developed by the CMFRI is a low cost indigenous formula involving a simple technology, which is suitable for production in the farm site itself. The cost of the feed is Rs 30 per kg (half the cost of imported feeds), and its FCR of 1.5 : 1 equivalent to that of the imported feeds, and is both farmer friendly and ecofriendly. Protein rich shrimp diets result in high nitrogen and phosphorus inputs into the effluents. Therefore, intensive shrimp farms currently tend to use feed in which the lipid level is increased from 8.5% to 13.5%, carbohydrate from 28.5% to 48.8%, and the protein level reduced from 40% to 20%. The use of such low-protein, high-lipid- high-carbohydrate, low-pollution shrimp diets coupled with increased aeration and probiotics in intensive shrimp farms has been found to be quite profitable and totally free from disease problems. Aeration and probiotics speed up aerobic decomposition of organic wastes and enrich the detrital food chain in shrimp ponds. There is also a tendancy to incorporate in shrimp feeds glucans which stimulate unspecified immune reaction in shrimp against a wide range of diseases (New, 1996).

Shrimp Aquaculture *vis-a-vis* Coastal Regulations Zone (CRZ) Rules and Regulations: The aquaculture policy recently declared by the Government of India (Ministry of Agriculture, 1992) ensures protection of the coastal environment. The policy gives extensive guidelines on how the coastal environment should be protected from possible pollution or other damages consequent on the setting up of aquaculture farms. While the CRZ rules prohibit any type of construction within the 500 m landward from the HTL (High Tide Line), the aquaculture policy demands ensuring sea front as a condition for starting a farm, which certainly involves construction. Since hatcheries are permitted within the CRZ, it is only logical that aquaculture is also regarded as a permissible activity within the CRZ, but with appropriate provisions for effluent treatment and reuse or control measures, on which the aquaculture policy pronounced by the Government of India is also quite eloquent. The relevant extracts from the concerned Acts, Rules and Notifications are stated below (i.e., The Notification dated the 19th February, 1991 framed under Section 3(1) and 3(2)(v) of the Environment (Protection) Act 1986 and Rule 5(3)d of Environment (Protection) Rules, 1986, Declaring coastal stretches as Coastal Regulation Zone (CRZ) and Regulating Activities in the CRZ).

a) The 1991 Notification imposes restrictions on industries, operations and processes in the CRZ, defined as the land between the low tide line (LTL) and the high tide line (HTL).

b) Under 2 (iii) of the 1991 Notification setting up and expansion of fish processing units including warehouse are prohibited. This restriction seems too harsh and unreasonable

c) Hatcheries, which inevitably require a waterfront are permissible

d) Para 3 (1) prescribes clearance for certain activities within the CRZ. Clearance shall be given for any activity within the CRZ only if it requires waterfront and foreshore activities. This implies that if the clearance is obtained from the Ministry of Environment, aquaculture farms can be set up. However restrictions prescribed under prohibited activities such as construction, land reclamation etc. impose unreasonable burden on the part of the farmers who inevitably require waterfront for the construction and operation of farms.

e) In category III of the CRZ between 200 m to 500 m, agriculture, horticulture, salt manufacture etc are permitted; aquaculture (aquatic agriculture) is obviously implied within agriculture as a permissible activity; construction of hotels/ beach resorts is also allowed with prior approval, in this zone. The Aquaculture (Regulation) Act 1995 of the State of Tamil Nadu permits aquaculture activity within the 500 m zone, albeit with some environmental safeguards. Moreover, it should be emphasised that the present coastal shrimp farming activities are restricted only to the salt-affected coastal areas totalling 2.07 million ha (Table 6), which would otherwise remain only fallow. With the introduction of shrimp farming, besides utilizing these fallow lands, considerable prosperity has been created in the rural coastal sector.

5. Present Status of Seafarming

There is no commercial seafarming activity in India at present. However, in order to promote seafarming, the CMFRI has established during 1995 a total of eleven experimental seafarms, one each at:

(1) Andhakaranazhi near Cochin for mussel and pearl culture

(2) Dalavapuram near Quilon for edible oyster culture

(3) Adimalathura near Thiruvananthapuram for mussel and pearl culture

(4) Tuticorin for pearl culture

(5) Tuticorin for edible oyster culture

(6) Mandapam for mussel and pearl culture

(7) Madras (Ennore) for mussel culture

(8) Dharmadam near Calicut for edible oyster and mussel culture

(9) Padanna near Calicut for edible oyster and mussel culture

(10) Mangalore for mussel culture

(11) Karwar for mussel culture

The seafarm (longline system) of 400 m^2 at Adimalathura has been installed over an artificial reef at a depth of 25 m. The results of these farms are quite encouraging and are dealt with in the subsequent sections. It should, however, be mentioned here that consequent on the establishment of these demonstration farms by the CMFRI, over 20 mussel and edible oyster farms have been established in late 1996 in the northern Kerala backwaters, estuaries and closeshore bays under financial support from IRDP-TRYSEM, and these farms are expected to be harvested in April-May 1997. Similar is the case with the Ashtamudi backwaters near Quilon where over a dozen edible oyster farms would come to the first harvest in January-February 1997 and the second harvest in May 1997.

6. Opportunities for Inland Saline Aquaculture

Results of the culture of marine fish and prawns in the saline soil ecosystems in Haryana (Tables 4 & 5) conducted by the Central Institute of Fisheries Education (CIFE), Bombay have indicated great potential for saline aquaculture in all the hinterland saline ecosystems which are estimated to be about 8.5 million ha (Table 6). Saline-alkali soils occurring in arid and semiarid areas in India are considered to be unfit for agriculture as the soluble salts are a great limiting factor. Special attempts have been made to utilise these lands for the culture of marine fish and prawns by tapping the ground saline aquifer through tubewells.

7. Diversification of Mariculture

Depending on the geographical and ecological diversities, there are vast differences in the availability and suitability of areas which can be developed for mariculture (land-based saline aquaculture and seafarming) and also in the candidate species available for cultivation. While the shrimps and the finfish (grey mullets, milkfish, pearlspot, seabass, groupers, red snapper, breams and pompanos) are suitable for farming along the entire Indian coast (particularly along the southwest and southeast coasts), the other items could be cultured along narrow geographical ranges; e.g., the seacucumber along the coasts of Tamil Nadu and Lakshadweep; pearl oyster along the coasts of Tamil Nadu (Gulf of Mannar & Palk Bay), Kerala, Gujarat, Lakshadweep & Andaman Islands; edible oyster in Andhra, Tamil Nadu, Kerala, Karnataka and

Table 4. Physicochemical properties of water in the Sultanpur (Haryana) saline aquaculture farm during 1984-85

Salinity	6.0 to 15.6 ppt
D.O	6.35 to 8.7 mg/l
CO_2	2.5 to 4.1 mg/l
pH	7.35 to 8.35
Temperature	5.8 to 36.8°C
Total alkalinity	90 to 117 mg/l

Table 5. Composite culture of fish and prawn in a 0.025 ha pond in the Sultanpur (Haryana) saline aquaculture farm during 1984-85

Species	Durat ion	Rates of stocking No./ha	Area (ha)	Stocking Size No. Stocked	Mean length (mm)	Mean weight (g)	Harvest Size Mean length (mm)	Mean weight	Total harvested weight (g)
Penaeus monodon	10 months	40,000	0.025	10,000	20	0.06	200	72.7	362.5
Mugil cephalus	10 months	10,000	0.025	2,500	25	1.0	400	525.5	787.5
Chanos chanos	10 months	10,000	0.025	2,500	25	1.0	415	520.0	842.5
Etroplus suratensis	10 months	15,000	0.025	3,750	30	1.75	150	140.0	542.5

The production rate was: *P. monodon*: 1450; *M.cephalus*: 3150; *C.chanos*: 3370; *E.suratensis*: 2170 kg/ha/yr

Gujarat; mussels in Andhra, Tamil Nadu, Kerala, Karnataka, Goa and southern Maharashtra; windowpane oyster and red clam in Andhra (Kakinada Bay); clams in Kerala, Karnataka, Goa and Maharashtra; and the seaweeds mainly in the Gulf of Mannar, Gulf of Kutch, Kerala backwaters, Chilka lake, Pulicat lake, and the lagoons and lakes in Lakshadweep and Andaman & Nicobar islands. However, it is very important to note here that the CMFRI's location testing efforts have proved beyond doubt enormous potential for pearl culture in Orissa, Andhra, Karnataka and southern Maharashtra in both onshore captive systems close to the shore and inshore seafarms.

8. Packages of Mariculture Practices

8.1. Microbial biotechnology for sustainable shrimp aquaculture

8.1.a. Shrimp diseases: Diseases seldom appeared as a major problem in the traditional extensive type of shrimp culture systems. But with the development of large scale farming, incidences of diseases and mortalities emerged as a major threat in most of the countries.

Many of the microbial agents of shrimp diseases form part of the natural microflora of marine and brackishwater ecosystems. These microbes are opportunistic pathogens and cause disease when shrimps are subjected to stress. Poor environmental conditions constitute the most important factor responsible for stress and disease in aquaculture systems. Shrimp diseases are caused by viruses, bacteria, fungi, parasites, algal toxins, mycotoxins in the feed, nutritional deficiency, adverse environmental conditions etc. (Fig. 5).

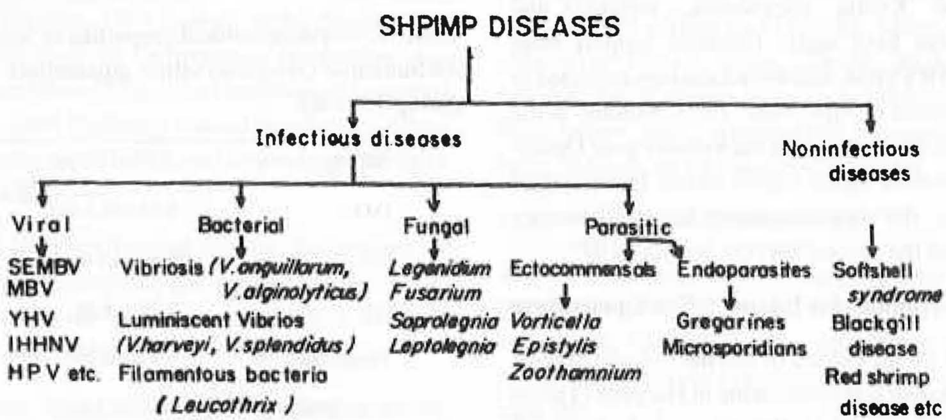


Fig. 5. Common shrimp diseases and their causes

Table 6. Salt-affected soils in India (area in '000 ha)

State	Coastal	Hinterland	Total
Andhra	283.3	530.0	813.3
Bihar	–	400.0	400.0
Gujarat	302.3	912.1	1214.4
Haryana	–	455.0	455.0
Karnataka	86.0	318.0	404.0
Kerala	26.0	–	26.0
Madhyapradesh	–	242.0	242.0
Maharashtra & Goa	88.0	446.0	534.0
Orissa	400.0	–	400.0
Punjab	–	519.5	519.5
Rajasthan	–	1122.0	1122.0
Tamil Nadu	83.5	256.5	340.0
Uttar Pradesh	–	1295.0	1295.0
West Bengal	800.0	–	800.0
Total	2069.1	6496.1	8565.2

(i) Viral diseases: Some of the important viruses known to affect P. monodon are: Monodon baculovirus (MBV), systemic ectodermal and mesodermal baculovirus (SEMBV), yellowhead virus, infectious hypodermal hematopoietic necrosis virus (IHHNV), hepatopancreatic parvo-like virus (HPV), lymphoid organ parvo-like virus (LOPV), type C baculovirus, baculovirus penae, reo- like viruses etc. Among these viruses, the whitespot disease causing virus, i.e., SEMBV caused severe economic losses in Japan, China, Thailand, Indonesia and India. In India, the disease was first noticed towards the end of 1994 along the east coast. The disease spread very rapidly to the other parts of the country and by 1995 almost all maritime states where shrimp culture was being carried out were affected by this disease. Apart from a number of shrimp species, this virus has been reported to affect other crustaceans including crabs and barnacles.

In the case of viral diseases, chemotherapy is not effective once the disease has set in because viruses are intracellular pathogens and any chemicals affecting viruses will affect the host tissue also. Hence, prevention of the disease is the most important strategy. The methods of prevention include stocking of healthy larvae maintence of good water quality and pond condition - disinfection by liming, chlorination, halogen treatment, use of iodophores, reservoir concepts etc. prevention of entry of carriers improving the disease resistance of the host using immunostimulants

(ii) Bacterial diseases: *Vibrio* spp are the most common among the various bacterial agents known to cause problems in shrimp culture. These bacteria are the predominant flora of the marine environment and several species such as *V.alginolyticus, V.parahaemolyticus, V.vulnificus etc.* have been involved in shrimp mortalities. Luminiscent vibrios, *V.harveyi* and *V.splendidus* cause severe mortalities in hatcheries. The filamentous bacteria such as *Leucothrix* may be found as ectocommensals and may cause mortality due to hypoxia and impairment of moulting.

(iii) Fungal diseases: Among the fungal pathogens of shrimp, *Legenidium* is the most prevalent in larval and early postlarval stages. Mortality may reach 100%. *Fusarium, Saprolegnia, Leptolegnia* etc. are the other fungal pathogens of shrimps.

(iv) Parasitic diseases: Ectocommensals such as *Epistylis, Vorticella* and *Zoothamnium* attach on the eyes, gills, appendages and body surfaces causing respiratory and locomotory difficulties. *Endoparasites* such as the gregarines and the microsporidians may cause mortalities.

(v) Non-infectious diseases:

(a) Chronic softshell syndrome - due to nutritional and environmental factors

(b) Red shrimp disease - due to the presence of aflatoxins in feed, poor water quality etc.

(c) Blackgill disease - due to the presence of toxic substances in water, organic loading etc.

(d) Dull hardshell disease - due to excessive calcium and phosphorus mobilisation as a result of overfeeding

Most of the disease control methods are based on preventive measures. They are:

(i) use of healthy postlarvae for stocking

(ii) quarentine measures

(iii) use of adequate balanced diet

(iv) use of genetically resistant stock

(v) use of immunostimulants

(vi) chemotherapy (chemicals and antibiotics must be used with utmost caution to minimise the danger of residual effects and development of antibiotic resistant strains)

8.1.b. Biotechnological tools for disease problems: Disease problems in aquaculture can be controlled with the application of various biotechnological methods. The four critical areas where microbiological and biotechnological approaches have impacted or will significantly impact aquaculture are development of tools for environmental management including the use of probiotics and bioremediation, development of sensitive, rapid and inexpensive diagnostic tools, development of vaccines against bacterial, viral and parasitic pathogens, development of tools for the nonspecific enhancement of immunity (immunostimulants).

The workhorses of biotechnology are the microbes, and today, they seem to provide many solutions to manmade problems. Biotechnological answers are emerging rapidly not only for detoxifying the environment through bioremediations, but also to enhance our natural resource utilisation by bioconversion and application of probiotics. The four major categories of biotechnological applications involved in solving environmental problems include: environmental monitoring bioremediation, ecoprotection.

(i) Environmental monitoring: Nearly 80% of shrimp diseases are caused by stress induced by environmental factors. Bioindicators (such as the Daphnia and trouts in freshwater systems) could be used as indicators of pollution. But bioindicators are difficult to maintain as they are extremely sensitive. Hence, single cells of an organism are used as biosensors. Toxins that affect the metabolism of microorganisms also affect their respiration. Production of carbondioxide leads to measurable pH changes. Rodtox is a biosensor developed in Japan for measuring the biological oxygen demand (BOD) which indicates the increased oxygen use by organisms or the toxins based on the inhibition of respiration. GBT Tox Alarm is a biosensor from Germany, which can detect even 0.1 ppm of cyanide. In the US, the luciferace enzyme from the firefly is used as a biosensor. It detects intracellular levels of ATP, the energy indicator of living organisms. However, these sensors could be used only to monitor the environment in batches, and not in a continuous mode.

(ii) Bioremediation and ecoprotection: Detection does not lead to cure. Hence, coupled with the use of biosensors, bioremediation has to be resorted to, using microbes of novel catalytic capabilities. Bioremediation steps include: (1) the selection of microorganisms possessing specific ability to detoxify unfavourable chemicals, (2) development of enzymes and proteins that can catalytically convert these wastes, and (3) bioprocess technology to harness these abilities. *Pseudomonas* strains detoxify through a number of enzymatic steps encoded by genes contained in their megaplasmids. Some strains also produce enzymes that can breakdown the nitrogenous compounds to ammonia and carbondioxide rather than to some other byproducts. Specific, nonpathogenic, pigmented, spore-forming bacterial species of *Bacillus* isolated from sediments of Pokkali ponds at Narakkal (Cochin) are found to inhibit the growth of pathogenic bacteria like *Vibrio anguillarum*, *Aeromonas* and *Escherichia coli* by competitive growth or by producing antagonistic antibiotics.

Table 7. Species of *Bacillus* of probiotic value

	Species	Characteristics
1.	*Bacillus cereus mycoides* (*Bacillus subtilis* group)	Colonies over the surface with curving filaments radiating out from the central growth, feathery appearance; growth may be dry, gummy, moist white, greyish white, yellowish, brown or black
2.	*Bacillus megaterium* (*Bacillus subtilis* group)	Colonies smooth white butyrus, shiny, rod shaped Gram-positive
3.	*Bacillus mucosis*	Colonies mucoid, semi-transparent, resmbling drops of paste
4.	*Bacillus agglomeratus*	Colonies small, round, greyish
5.	*Bacillus cartilaginous*	Colonies thick, round & compact, and could be lifted from the agar entirely
6.	*Bacillus idosus*	Colonies dry lustreless and laminated, finely wrinkled
7.	*Bacillus intrieatus*	Colonies widespread, whitish, flat, mycelium -like ingrowth into the agar, containing filaments with numerous septa.

Colonies of spore-forms of *Bacillus* of probiotic value, most often observed in the aquatic environments, have been identified to be the 7 species shown in Table 7. All of them can be mass cultured and used as probiotics in their logarithmic phase when their enzyme potential is maximum. They exhibit antagonism towards other heterotrophs, and hence, could be successfully used as probiotics to control microbial diseases in aquaculture ponds. As they are highly proteolytic, they easily mineralise the faecal matter and left-over feed putrified by other heterotrophs. By active mineralisation the pond environment is made clear. *Bacillus* can act as a host defence barrier by making the target epithelial cells unavailable to pathogens through competitive exclusion. The antibiotics produced by these seven species are environment friendly. The *Bacillus* strains are biodegradable after their activity. The most effective mode of action of *Bacillus* is now known to be by immunostimulation.

The performance of *Bacillus* is influenced by the inoculum level, species of shrimp or other organisms tested, stage of maturity, level of stress and quality of the rearing pond environment. Because of this wide spectrum of variables, there is a broad range of response to probiotics and the plethora of positive responses span a wide range of experimental protocols.

According to Moriarty (1996), microbial ecology and biotechnologies have advanced to the point that commercial products and

Table 8. Commercial probiotic products and immunostimulants used by the aquaculture industry

	Probiotics	Manufacturers/country	Price(Rs)	Quantity
1.	DMS 1000 series	ARDA-TEK Australia	3,000	5 litres
2.	Synerbac	-do-	-do-	-do-
3.	Wunapuo-15	Team Aqua Corpo-ration, Thailand	6,000	25 kg
4.	Biostart™ Bio-brews	USA	5,000	5 litres
5.	Aqua bacta aid products	Water Quality Sciences International Inc., USA	–	–
6.	Aquakalgon+	Wockhardt Ltd (India) in collaboration with Techniques et Biochimie Appliques (TBA), Paris.	–	–
7.	Aqua buck up	Ecomax India	5,000	5 kg
8.	Spec™ bac	Proposed by CMFRI	5,000	5 kg
9.	Immustim (purified Beta 1,3-D-glucan)	Immu Dyne Inc. USA	–	–
10.	Aquastim	College of Fisheries, Mangalore, India	–	–

Nutrient cycling in the water column and pond bottom accelerated by the addition of probiotic products

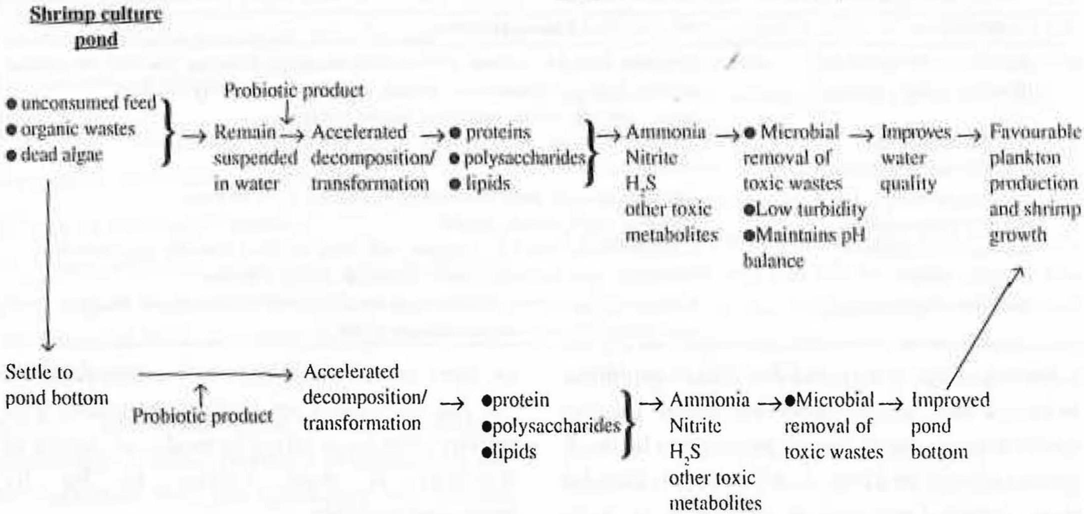


Fig. 6. Nutrient cycling in the water column and pond bottom accelerated by the addition of probiotic products

technologies are available for treating large areas of water and land to enhance population densities of particular microbial species or biochemical activites. The bacteria that are added must be selected for specific functions that are amenable to bioremediation and added at a high enough population density and under the right environmental conditions. The efficacy of bioremediation and probiotics depends on the nature of competition between species or strains of bacteria. A normal shrimp culture pond has many different types of microorganisms. The most numerous types are those that are very efficient at reproducing themselves. These types make use of the detritus that accumulate on the pond bottom and rapidly build up their biomass by growing and replicating themselves. But, what is desired is a major reduction in the detritus without the growth of biomass. In otherwords, the types of bacteria that we want in the system are those that are less efficient at reproducing themselves, but are highly efficient at reducing the amount of detritus in the pond (Fig. 6). A variety of probiotic products are commercially available and are used by the aquaculture industry for environmental management (Table 8).

(iii) Immunostimulants: Most of the immunostimulants used are of fungal or bacterial origin (viz., B1, 3-glucan derived from fungal or yeast cell wall; lipopolysaccharides and peptidoglycan derived from bacterial cell wall). These compounds stimulate the nonspecific defence system in the crustaceans by the activation of the prophenol oxidase system (resulting in the production of melanin at the site of infection which possesses antimicrobial properties), stimulation of phagocytosis and encapsulation. However, the efficacy of these immunostimulants against viral infections still needs further investigations.

Immustim is an immunostimulant developed by Immu Dyne Inc., USA, for shrimps and marketed worldwide. The College of Fisheries, Mangalore has developed a similar product called aquastim which has been successfully applied in commercial farms (Dr. I. Karunasagar, personal communication). As the immune system in shrimps is rather weak, weekly application of aquastim is necessary.

Table 9. Economic profile of trade in pearls in India and transfer of technology by CMFRI

- India's total pearl production	:	20 kg SPIC 13 kg; TNFDC 2 kg; Pancharatna 5 kg
- Country's imports annually	:	725 kg, worth Rs. 290 million
- Production target by pearl culture in India	:	1000 kg, worth Rs. 500 million
- Japan's pearl production	:	63,375 kg marine
- China's pearl production	:	199,500 kg freshwater
- USA's pearl production	:	9,375 kg marine
- World production	:	276.6 t (199.5 t freshwater; 77.1 t marine)

Table 10. Development of pearl culture technology in India by the CMFRI

		Year	Location & Results	
I. First pearl production in India	:	July, 1973	Tuticorin, Gulf of Mannar Tuticorin,	
II. First hatchery production of pearl oyster in India	:	August, 1981	molluscanshellfishhatchery	
III. Development of land-based pearl culture technology	:	1995	Kakinada, Visakhapatnam, Madras & Mandapam	
IV. Successful location testing for site selection for pearl production	:	1976	Vizhinjam Bay, Kerala	
		1985	Mandapam, Tamilnadu	
		1986	Lakshadweep	
		1987	Gujarat	
		1994	Calicut, Andhakaranazhi (Cochin)	
V. Number of pearls produced by CMFRI through an investment of Rs. 8,10,500 at Tuticorin	:		No. of pearl oysters harvested	No. of pearls obtained
		1973-1978	605	428
		1978-1983	768	443
		1983-1988	3576	1390
		1988-1995	6365	2171
		1995 -1996	7583	2666
Number of pearls sold	:	1994 -1996	1173 (180.72 g) for Rs. 1,28,668	
VI. Technology transfer experiments at Valinokkam, Gulf of Mannar	:	1-7- 1991 to 11-8-1992		
Total expenditure	:	Rs. 36,312		
Total pearls produced	:	1,849		
Pearls given to farmers as wages	:	250		
Balance pearls sold	:	1,599		
Revenue earned	:	Rs. 73,134		
VII. Establishment of Tamil Nadu Pearls Ltd.				
Duration	:	4 years		
Total expenditure	:	Rs. 6.9 million		
Pearls produced	:	13 kg		
Pearls sold	:	4 kg for Rs. 0.782 million		
VIII. Sponsored projects for pearl culture				
1. Donor	:	Department of Ocean Development		
Year of allocation	:	1995		
Amount	:	Rs. 2.5 million		
Location	:	Mandapam Camp		
2. Donor	:	ICAR		
Year of allocation	:	1996		
Amount	:	Rs. 3.0 million		
Period of operation	:	8 years		
Location	:	Mandapam Camp		
3. Donor	:	Dept. of Biotechnology		
Project	:	Tissue cultured marine pearls		
Period of operation	:	May, 1994 to May, 1997		
Amount	:	Rs. 2.207 million		

8.2 Pearl oyster farming and pearl production

The world production of marine pearls was 78 tonnes valued at US $ 1092 million during 1993. Japan still holds the monopoly in the production of marine pearls. Although India had the distinction of developing the cultured pearl technology in 1973, it could not commercially produce pearls for world trade. The country has ample scope to develop and expand the cultured pearl industry in different locations along both the west and east coasts and the Andaman & Lakshadweep waters (Tables 9 & 10).

MOU's signed or proposed by CMFRI during 1996 for transfer of pearl culture technology

1) NCC Blue water, Chandanada, Andhra Pradesh
2) Gem Holiday Resorts Ltd., Madras, Tamil Nadu
3) Balaji Bio-tech Ltd., Nellore, Andhra Pradesh
4) M/s Sterling Shrimpex (P) Ltd., Chirala, Andhra Pradesh
5) Mr. Jagadeswara Rao, Visakhapatnam, Andhra Pradesh
6) Smt. V. Sarala, Visakhapatnam, Andhra Pradesh
7) M/s Aqua Prime International, Nellore, Andhra Pradesh

Six species of pearl oysters, namely, *Pinctada fucata* (Gould), *P. margaritifera* (Linnaeus), *P. chemnitzi* (Philippi), *P. sugillata* (Reeve) and P. atropurpurea (Dunker) have been recorded in the Indian waters. Among these, *P. fucata* is the most dominant species. It occurs in large numbers in pearl oyster banks known as 'paars' in the Gulf of Mannar and in the intertidal reefs known as 'khaddas' in the Gulf of Kutch. *P. fucata* is the only species which has contributed to the pearl fisheries in these two gulf regions. Along the southwest coast of India, particularly at Vizhinjam

Table 11. Expected economics of onshore marine pearl culture in the urban vicinity of Visakhapatnam (project started in late 1996)

(A) Nonrecurring (capital investment)		Rs.
Cost of land (1 ha)	:	10,00,000
Cost of 16 tanks of 4,000 m^2 total with hard bottom and roof (@ Rs. 250/m^2 per tank)	:	10,00,000
Cost of backyard hatchery	:	5,00,000
Cost of pumping, aeration and associated structures	:	3,00,000
Power installation and generator	:	2,00,000
Cost of algal production system (100 l/day)	:	2,00,000
Cost of oyster cages and suspending materials	:	10,00,000
Instruments for lab	:	2,00,000
Total	:	44,00,000
(B) Recurring (working capital)		
Wages	:	6,00,000
Nuclear beads	:	5,00,000
Instruments for implantation	:	50,000
Chemicals and glassware	:	1,50,000
Power charges	:	50,000
Repairs and replacement	:	50,000
Total	:	14,00,000
Repayment of term loan (A) with interest spread over 5 years	:	1,30,000
Grand total	:	27,00,000
(C) Revenue		
Total gross return from 1,25,000 pearls @ 25% yield and Rs. 40/pearl (total implanted oysters 5,00,000)	:	50,00,000
(D) Net profit (C - B)	:	23,00,000
Percentage of profit	:	85.2

and Calicut, large numbers of spat of *P. fucata* have been collected from mussel culture ropes in the 1980s. *P. margaritifera* is confined mostly to the Andaman Islands where it is common in some places, but it also occurs in the Vizhinjam bay in stray numbers. From the Lakshadweep, spat of *P. anomoides* has been recorded on the ridges of rocks and corals.

Raft culture, rack culture, onbottom culture and onshore culture are the 4 methods of rearing pearl oysters. Pearl oysters can be successfully reared in 50 t capacity concrete tanks filled with clean seawater. Mother oysters/seeded oysters numbering a minimum of 5 lakhs (maximum of 10 to 15 lakhs) can be successfully stocked and grown in tanks of 4000 m^2 each, with a depth of 1.5 to 2 m (Table 11). Besides the above four methods, longlines and underwater platforms are also used in some parts of the world.

The colour of the cultured pearls largely follows the colour of the nacre of the shell of the pearl oyster which produces the pearl and is genetically determined. Besides this, the nature of the culture site, depth, light penetration, feed, water quality, and the minerals and trace elements in the seawater also determine the pearl colour to some extent. Graft tissue preparation is also an important factor in determining the quality of pearls. Now a days in Japan, various chemicals and drugs are used to condition the oysters and make them grow healthy and produce good quality pearls. For obtaining good quality pearls in the seafarms, the oysters should be grown at depths of 5 to10 m. Strong sunlight on oysters must be avoided since sunlight can induce nacre secreting cells to produce calcite crystals to form prismatic layer over the nucleus resulting in poor quality of pearl. Alternatively, pearls could be grown in shallow depth of 1 to 2 m in onshore lands and seafarms by appropriately shutting off the natural light (Figs 7 to 10). There is very high potential for the culture of half pearls by implanting a number of half beads in holes made on the same shell; after implantation the oysters are released in the growouts, where the mantle secretes the nacre around the beads, resulting in pearls. The advantage in half pearl production is that it is equally costly or even costlier than full pearl, the technique is much less demanding in skill and upto 10 half pearls could be produced from a single oyster. Half pearl production will be part of the consultancy package proposed to be offered by the CMFRI since 1997.

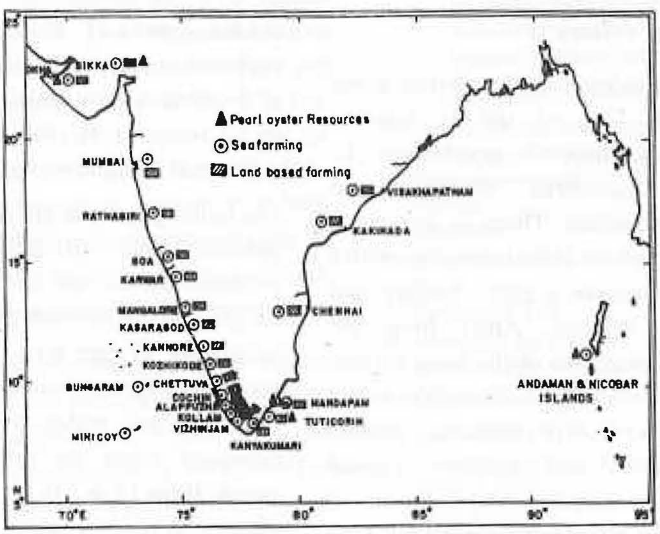


Fig. 7. Pearl culture prospects in India

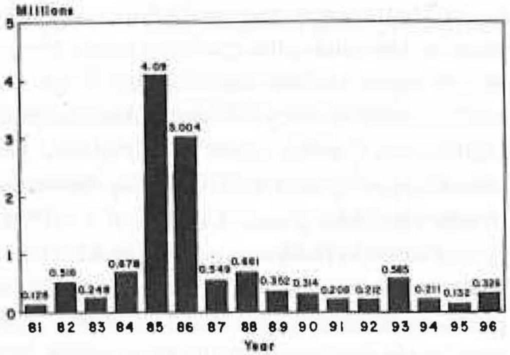


Fig.8. Pearl oyster spat produced at CMFRI hatchery

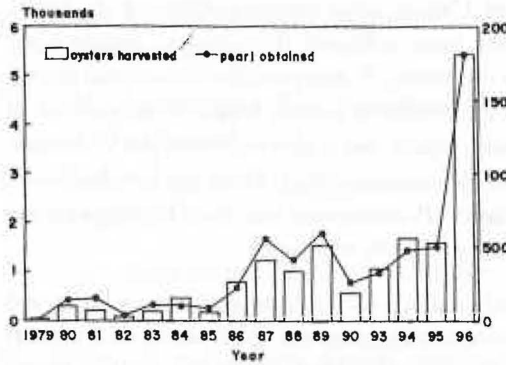


Fig.9. Pearl production in CMFRI farm at Turicorin

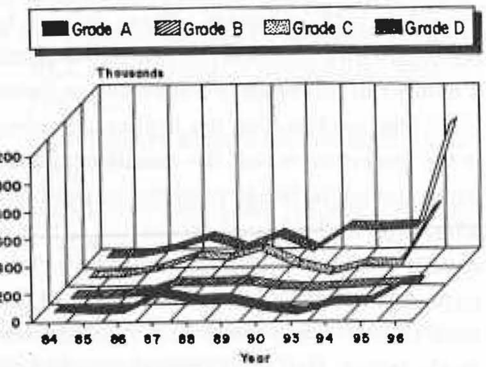


Fig.10. Grade-wise production of pearls

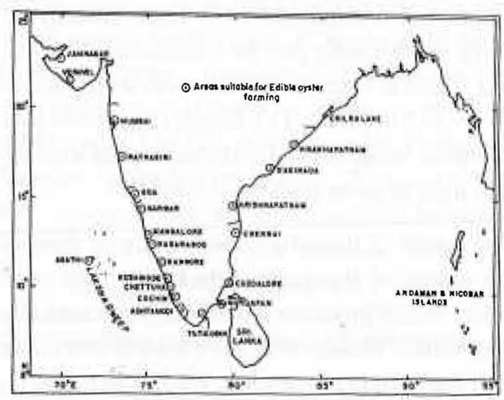


Fig.11. Distribution of edible oyster in India and areas suitable for oyster farming

8.3. Edible oyster culture

The edible oysters enjoy wide distribution along the Indian coast. Out of the six species, *Crassostrea madrasensis, C. gryphoides, C. rivularis and Saccostrea cucullata* are commercially important. There is increasing interest in oyster culture in the tropical countries in recent years as they are a great delicacy and there is growing demand. Apart from the edibility of the meat, the shells have various industrial and agricultural uses. The edible oysters are euryhaline and occur in estuaries, creeks, backwaters, lagoons and shallow coastal waters. *S. cucullata* is a purely marine form. *C. gryphoides* occurs along north Karnataka, Goa and Maharashtra. *C. rivularis* occurs along the coastal creeks of Gujarat where they are exploited mainly for the shells. *S. cucullata* is distributed throughout the Indian coast on rocky substrata in shallow intertidal areas and withstands surf and wave action (Fig. 11).

The farming methods are broadly divided into: (i) onbottom and, (ii) offbottom culture. In the onbottom culture, the seed oysters are sown on the ground. The methods involved in off-bottom culture are: (1) rack & tray, (2) rack & string, (3) stake, and (4) raft. Oysters reach harvestable size (above 80 mm) within 10 to 12 months. They are harvested when the meat attains fairly good weight (Figs 12 & 13).

Production rates differ according to the culture methods. Through the rack & tray method, the

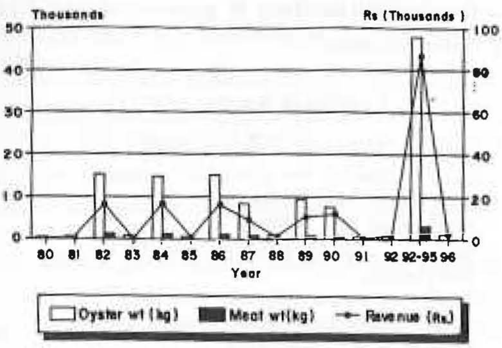


Fig.12 Oyster production and revenue earned by CMFRI at Turicorn (1979-95) and Dhalavapuram (1994-95)

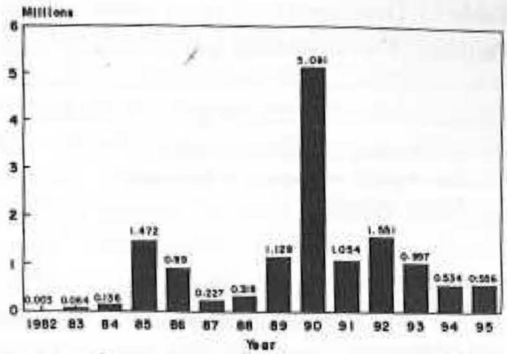


Fig.13 Edible oyster spat produced at the CMFRI Turicorn hatchery

estimated production was 120t/ha/yr at Tuticorin during 1980-86 and by the rack & string method, it was 80 to 105 t/ha/yr at Dhalavapuram in the Ashtamudi lake (Quilon) during 1994-95. The production rate through the stake method was 20 t/ha/yr at Tuticorin in 1980-86. In the rack & tray method the rate of return on investment was 30% and by the string method it was 44.8%. In an area of 1 ha, 24 units of 300 m^2 each can be accomodated as in the CMFRI's demonstration farms at Tuticorin and Dhalavapuram in the Ashtamudi lake (Quilon) (Table 12). The cost of materials depends on the prevailing market rates. Production of meat and shell per hectare is estimated to be 10.2 tonnes and 81.6 tonnes respectively. There is good demand for live shellon oysters in the international market and the cost of 100 shellon oyster is Rs. 25. The international export market value of 1 kg of chilled/frozen oyster meat varies from Rs. 125 to 300. The empty oyster shells contain 52 to 55% calcium oxide and are used in the manufacture of calcium carbide, lime and cement. The shells are crushed to suitable size and used as poultry grit.

The progressive development of edible oyster hatchery and growout technologies achieved by the CMFRI is outlined in Table 13. The experimental work carried out by the CMFRI at Athankarai (Mandapam Camp), Pulicat lake and Tuticorin in Tamil Nadu, Kakinada Bay and Bheemunipatnam in Andhra Pradesh, Goa, Mulky estuary in Karnataka and Ashtamudi lake and Dharmadam estuary in Kerala gave highly encouraging results, suggesting commercial feasibility of edible oyster culture along the east and west coasts of India.

Table 12. Production and economics of edible oyster farming by rack and ren method at Dalavapuram in a 300 m^2 area during 1995

	Amount in Rs.
I. Material cost	
(a) Poles	
Horizontal poles 6 m x 30	: 1,200
Horizontal poles 2 m x 9	: 120
Vertical poles 3 m x 126	: 2,520
Total	: **3,840**
(b) Nylon ropes and strings	
Nylon rope for strings and racks 40 kg	: 2,800
Number of strings 1060	: 110
Total (a+b)	: **6,750**
II. Labour cost and other charges	
Fabrication of oyster strings	: 480
Fabrication of racks	: 240
Harvest	: 640
Depuration	: 640
Shucking	: 880
Total	**2,880**
Total cost (I + II)	**9,630**
III. Production and revenue	
Shellon weight of oysters	: 4.25 tonnes
Meat weight (10%)	: 425 kg
Value of meat @ Rs. 30/kg	: Rs. 12,750
Value of shell @ Rs. 350/tonne (80% of 4250 kg)	: Rs. 1,190
Gross revenue	: 13,940
IV. Net profit (III - I + II)	: 4,310

Table 13. Development of oyster culture technology in the shellfish hatchery & growout of CMFRI at Tuticorin, Gulf of Mannar and technology transfer to other locations

		Year	Location & Results
1.	Development of growout technology	1977	Tuticorin, Molluscan shellfish hatchery
2.	Development of hatchery technology	1982	- do -
3.	Oyster production	1979- 1996	Total weight = 1,23,341 kg Meat weight = 8,369 kg Revenue = Rs. 2,00,504
4.	Spat production	1982- 1996	14.52 million
5.	Lab -to- Land programme on oyster farming	1979	2 t shellon oyster produced in farmers' holdings Revenue earned Rs. 8587.50
6.	Sponsored project by NABARD for Rs 8,58,200 for technology demonstration	1992-1995	Harvest = 47,756 kg (shellon) Meat weight = 2,946 kg Revenue earned = Rs. 95,339
7.	Areas found suitable for oyster farming based on site selection experiments (good growth rate and survival in all these places)	1993-1994	Ashtamudy estuary Kerala Munambam " Korapuzha " Dharmadam " Karwar Karnataka
8.	Demonstration farms	1994-1996	1) Dalavapuram farm in Ashtamudi = 0.2 ha 2) Chetuvai farm = 0.03 ha 3) Narakkal farm = 0.02 ha 4) Dharmadam farm = 0.04 ha - good spat production from wild - yield in rack & string method = 80 t/ha - good growth rate and 8-10% meat yield within 6 to 7 months
9.	Private oyster farms adopting CMFRI farming technology	1995-96	7 farms at Dalavapuram = 0.03 to 0.2 ha each 1 farm at Munambam = 0.04 ha 1 farm at Padanne = 0.04 ha
10.	Mixed farming trials	1995-96	-oyster seed for farming obtained from the wild - seed from Dalavapuram transported to Munambam, Narakkal, Chettuvai, Dharmadam, Padanne and Lakshadweep. -good survival and growth of transplanted seed. At Dharmadam and Padanne -green mussel grown in edible oyster racks -good growth rates and survival from December to May 2.5 t of mussels harvested from Padanne, 1 t from Dharmadam in May, 1996 and sold @ of 14/- per kg shellon -About 20 new private farms supported by IRDP-TRYSEM established in the north Kerala estuarine waters in late 1996, expected to yield over 150 tonnes of mussels and about 200 tonnes of edible oyster in May 1997

8.4. Mussel culture

The green mussel *Perna viridis* and the brown mussel *P. indica* are the two species occurring along the Indian coasts. The green mussel enjoys a wider distribution along the east and west coasts of India including the Andaman Islands, whereas the brown mussel is restricted to the southwest coast of India. Along the east coast, the green mussel is found on small beds in the Chilka Lake, Kakinada, Madras, Pondicherry, Cuddalore and Porto Novo while along the west coast it forms extensive beds around Quilon, Alleppey, Cochin, Calicut to Kasargod, Mangalore, Karwar, Goa, Bhatia creek, Malwan and the Gulf of Kutch (Fig. 14).

Methods currently followed in mussel culture in the tropical and temperate waters fall into four categories: (1) the sea bottom culture, (2) pole culture, (3) suspended (raft) culture, and (4) longline culture. The longline culture is more profitable than the raft culture (Tables 14 & 15).

The advantage of mussel culture in our tropical waters compared to the temperate seas is that the rate of production is very high in the former. In European waters the seeds attain marketable size in a period of 12 to 36 months while it takes only 5 to 6 months in India because of the faster growth and high productivity in the tropical waters (Table 16).

8.5. Clam culture

A number of clam species belonging to the families Arcidae, Veneridae, Corbuculidae, Tridacnidae, Solenidae, Mesodesmatidae, Tellinidae and Donacidae are exploited along the Indian coast. The cultivable species belong to the first four families mentioned above. They include *Anadara granosa, Meretrix meretrix, Katelysia opima* and *Paphia laterisulca, Villorita cyprinoides,* and *Tridacna marina.* Of all the maritime states, Kerala leads the country in clam production with a current annual catch of 32,927 t which accounts for 72.5% of the total clam landings. The current annual clam landings in Karnataka is estimated at 6,592 t although considerable fluctuations in the landings have been recorded. The clam production in Goa has been estimated at 887 t/year and that of Maharashtra at 1,100 t/year. Along the east coast

Table 14. Production rates achieved in mussel culture by different methods in various centres

Species	Place	Production rate	Period	Raft	Long-line	Rack
Perna viridis	Calicut (opensea	4.4 to 12.3kg/m of rope	5 months	+	–	–
"	Karwar(bay)	7.6 to 10 kg/m of rope	5 to 6 months	+	–	–
"	Goa (NIO) (bay)	6 kg/m of rope	6 months	+	–	–
"	Ratnagiri (opensea)	7 kg/3 m of rope	6 months	+	–	–
Perna indica	Kovalam, Madras (opensea)	6.6 kg/m of rope	4 months	+	–	–
P. viridis	Vizhinjam (bay)	10 kg/m of rope	7 months	+	–	–
P. viridis/ P. indica	Andhakaranazhi (opensea)	10 kg/m of rope	6 months	–	+	–
P. viridis	Padanne	10 kg/m of rope	6 months	–	–	+
P. viridis	Dharmadam	10 kg/m of rope	5 months	–	–	+

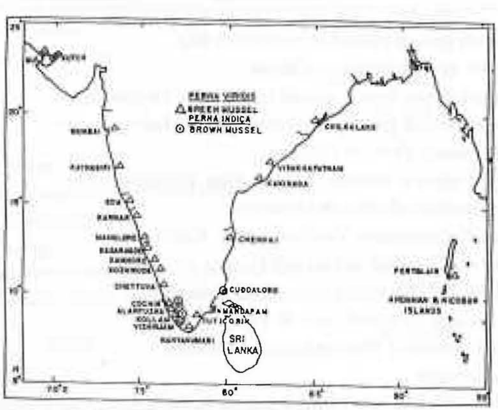


Fig.14. Distribution of green and brown mussel in India and areas suitable for farming.

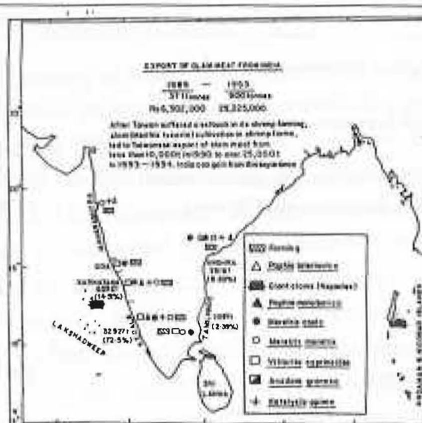


Fig.15. Distribution of clams in India and farming areas

Table 15. Economics of open sea mussel farming (0.36 ha area) (longline method)

I. Initital investment		Rs.
Cost of construction of a longline unit (floats, anchors, anchorline, horizontal & vertical lines)	:	1,28,000
Floating platform for watch & ward	:	25,000
FRP dinghi & OB engine	:	75,000
Spat collectors	:	10,000
Others	:	12,000
Total	:	2,50,000
II. Fixed cost (for one crop of 6 months only per year)		
Depreciation @ 33.3%	:	83,250
Interest @ 18%	:	45,000
III. Operational cost (per crop)		
Seed	:	30,000
Materials (cotton cloth, cement block, etc.)	:	15,000
Labour	:	1,33,000
Miscellaneous	:	22,000
Subtotal		2,00,000
IV. Total cost (annual) (II + III)	:	3.3 lakhs
V. Expected production	:	55 tonnes
VI. Gross revenue at Rs. 10/kg	:	5.5 lakhs
VII. Net profit (VI - IV)	:	2.2 lakhs

of India, the clam resources are of smaller magnitude. In Tamil Nadu, the Vellar estuary and the Pulicat Lake together contribute annually 1087 t, while in Andhra Pradesh, the annual clam production was estimated at 2816 t (Fig.15).

Since clams are cultured on the bottom, site selection depends on the substratum. The occurrence of natural clam populations is indicative of the suitability of the site with particular reference to the tide level, substratum and salinity. Clam farms are located in estuaries, bays and other sheltered areas close to the shore. Clams are rarely grown in ponds, but in recent years, due to the disease problems in shrimp farms, there is growing interest in many Southeast Asian countries to utilize the shrimp ponds for clam culture. In Taiwan, *Meretrix lusoria* is grown in ponds, formerly used for milkfish and shrimps and also in the outlet and inlet canals of these ponds. As a result, Taiwan's export of clam meat which was less than 10,000 tonnes during 1990 exceeded 25,000 tonnes during 1994. The results of hatchery production of clam seed (Fig.16), farming and ranching achieved by the CMFRI since 1978 (Table 17) suggest good scope for the expansion of clam farming in shrimp farms and in protected natural waters (Table 18).

India's export of clam meat has been increasing steadily over the past few years, particularly to Japan, Western Europe and USA. The export increased from a meagre 371 t in 1989 to 800 t in 1993 (Table 19). In terms of value, almost five fold increase has been recorded from Rs 63.02 lakhs in 1989 to Rs 292.25 lakhs in 1993.

Table 16. Progressive development of mussel culture technology in India by the CMFRI

		Year	Location & Results
I.	Culture technology	1973	Brown mussel culture at Vizhinjam Bay
		1974	Green mussel culture at Calicut
II.	Hatchery technology	1984	Experimental brown mussel hatchery at Vizhinjam
		1985	Experimental green mussel hatchery at Madras
III.	Lab-to-land programme on mussel culture	1979	Pilot scale culture at Calicut
IV.	Experimental mussel farming	1976-82	Raft culture at Madras, Karwar, Goa, Ratnagiri, Tuticorin, Andaman and Nicobar Longline culture at Visakhapatnam, Kakinada, Andakaranazhi (Cochin) and Karwar Result 1.5 t harvested from Andakaranazhi in January 1996 and sold @ 14/kg
		1995-96	Rack culture at Dharmadam and Padanne in estuaries
V.	Production rate achieved		10 kg/ 1/2 year/one metre string on an average in all farms
VI.	Sponsored projects for mussel hatchery	1994-97	Sponsored by the Dept. of Biotechnology

Table 17. Progressive development of clam culture technology in India by the CMFRI

	Year	Location & Results
1. Farming technology	1978	Farming of ***Anadara granosa*** at Kakinada: 0.39 t/100 m^2/5 months = 39 t/ha 2.6 t/625 m^2/5.5 months = 41.6 t/ha 6.1 t/0.16 ha/7 months = 38.1 t/ha Survival = 88.6%
2. Hatchery technology	1987	Developed at the Tuticorin shellfish hatchery for *Villorita cyprinoides* and *Meretrix casta*
3. Pilot scale seed production	1987	At Tuticorin shellfish hatchery for *Meretrix meretrix*
	1988	- do - for *Anadara granosa* and *Meretrix casta*
	1988-1996	- do - for *Paphia malabarica* (35,000 to 1.54 million seed per year)
4. Searanching of clam seed	1989-1996	At Ashtamudi, Madras.Tuticorin, Munambam & Pondicherry Production (P. malabarica) at Ashtamudi : 1.425 kg to 5.93 kg/m^2/3.5 months Survival 7.05 to 17.64%
5. Sponsored projects for clam hatchery and ranching	1993-1995	Donor : Marine Products Export Development Authority: Amount : Rs 0.362 million Total seed produced = 1.54 million Places where sea ranched = Ashtamudi. Munambam & Ayiramthengu
	1994-1997	Donor : Dept. of Biotechnology Amount : Rs. 0.8 million Seed produced = about 1 million

Table 18. Economics of clam culture

A. Capital expenditure		Amount in Rs.
1. FRP boat with outboard motor	:	80,000
B. Operational cost		
1. Casurina poles	:	2,500
2. Pen enclosure	:	10,000
3. Seed @ Rs 55/1000	:	16,50,000
4. Running cost of boat	:	6,000
5. Labour	:	6,000
6. Harvesting, depuration & shucking of meat	:	50,000
7. Contingencies	:	6,000
8. Salary to Manager @ Rs. 2,000 for 6 months	:	12,000
9. Watch and ward for 6 months	:	12,000
Total	:	17,54,500
C. Interest at 15% for A for one year	:	12,000
D. Cost of production		
1. Depreciation @ 10% of A	:	8,000
2. Operational cost	:	17,54,500
3. Interest	:	12,000
Total	:	17,74,500
E. Income		
Shellon weight of harvested clams	:	700 t
Wet meat weight	:	105 t
Shell weight	:	525 t
Sale of 105 t meat @ Rs. 25,000 per ton	:	26,25,000
Sale of 525 t shell @ Rs. 1,000 per ton	:	5,25,000
Total	:	31,50,000
F. Profit		
(Rs. 31,50,000 - Rs. 17,74,500)	:	13,75,500
Net profit on investment	:	77.5%.

8.6. Lobster farming

Spiny lobsters (rock lobsters) are low volume, but high value fisheries which support some of the most valuable marine fisheries resources worldwide. India earns approximately US $ 15 million each year through the export of lobsters (Fig.17). Though the lobsters are widely distributed along the Indian coast, the major fisheries are located along the northwest (Maharashtra & Gujarat), the southwest (Kerala & Tamil Nadu) and the southeast (Tamil Nadu) coasts. Among the six shallow water species, only *Panulirus polyphagus, P. homarus and P. ornatus* are exploited in commercial quantities.

The technology of lobster farming and fattening is already well developed, and the economics quite encouraging (Table 20). High demand for live and whole cooked lobsters in the international market and the high price offered, make lobster farming an attractive industry. However, in the absence of a viable hatchery technology and only limited availability of juveniles and subadults from the wild, scaling up the farming activity has not been possible. The CMFRI has been able to successfully breed the spiny lobsters and rear the phyllosoma upto the VIth

Table 19. Export of clam meat

Products		1989	1990	1991	1992	1993
Dehydrated Clam meat	Q:	42	107	164	129	124
	V:	933	2,546	4,789	3,855	5,669
Frozen Boiled Clams	Q:	329	414	1,232	940	776
	V:	5,369	7,558	37,392	31,028	23,541
Clam meat Pickle	Q:	–	–	–	37	NEG:
	V:	–	–	–	2,025	15

Q = Quantity in tonnes; V = Value in Thousand

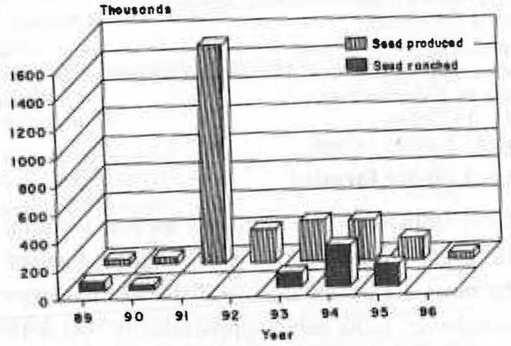


Fig.16. Production of *Paphia malabarica* seed in CMFRI hatchery

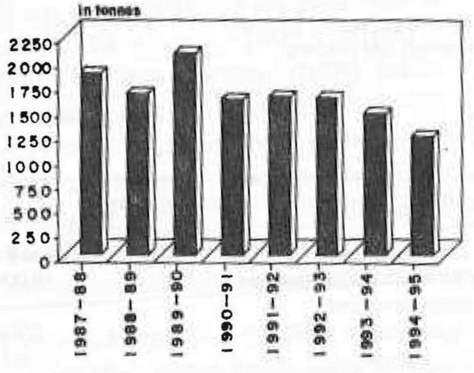


Fig.17. Export of lobster tail during 1987-88 to 1994-95

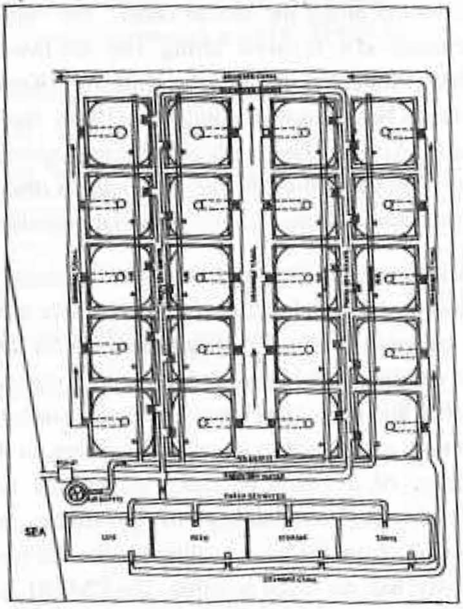


Fig.18. Layout of an indoor lobster culture facility developed for the industry by the CMFRI

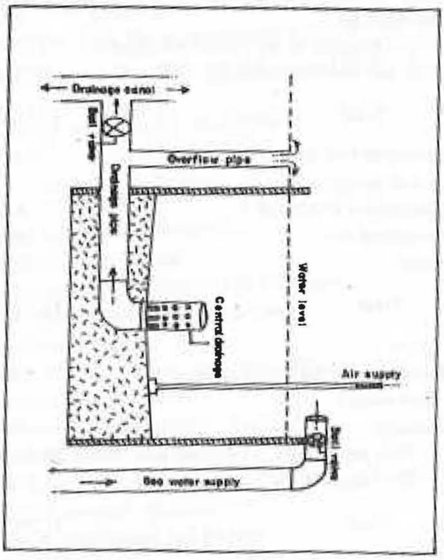


Fig.19. Schematic diagram of a lobster culture tank developed for the industry by the CMFRI.

Table 20. Economics of spiny lobster culture for producing one tonne lobster in indoor system

Assumptions: Species - *Panulirus ornatus*, duration of culture - 6 months, size at stocking - 150 g, size at harvest - 500 g, mortality - 10%

		Rupees in lakhs
A.	Capital cost Construction of tanks and overhead shed; pumps, air blowers and generator; erecting pump house and pumping system; PVC pipes and fittings for water and air distribution; construction of sump and filtration system, etc.	12.00
B.	Operating cost Juveniles, feed, electricity, chemicals & antibiotics and lobster shelters; wages to labourers and miscellaneous expenses	4.00
C.	Gross profit from selling 1000 kg lobsters @ Rs. 800 per kg	8.00
D.	Net profit (depreciation of capital, construction and equipments excluded)	4.00

stage as early as 1978. This work which was suspended after the cyclone devastation of the Institute's mariculture laboratory at Kovalam (near Madras) in 1980 is now being revived with a view to completing the life history successfully, paving the way for a viable hatchery system.

In the matter of growout, eyestalk ablation experiments have shown that a group of lobsters of 85 g average weight, after eyestalk ablation, increased to 432 g in 165 days as compared to the growth increment of only 57 g for the control group. A lobster growout system designed by the Institute for the Amalgam Seafood Exports Cochin consists of a series of circular or square cement tanks of 9 to 16 sq.m area each with either a flowthrough or a semiclosed recirculation system (Figs 18 & 19).

8.7. Crab culture

During the period 1989-94, India has exported live mud crabs to the tune of about 630 tonnes valued at Rs. 2.58 million on an average annually. Among the maritime states, Tamil Nadu, Andhra Pradesh and Kerala have already taken up crab farming as an alternative source of income generation in the coastal rural sector. Indo-Pacific in distribution, the mud crabs inhabit

Table 21. Economics of three systems of mudcrab farming under taken in the Mother crab farm at Tuticorin

Culture method	Production & income	Expenditure	Net profit/crop
Monoculture 0.5 ha	Crabs 780 kg Rs. 1,57,200	Cost of seed, feed fencing, power supply wages etc. Rs 43,860	Rs 1,13,340 (120 days)
Polyculture 0.5 ha	Crabs 1140 kg Rs 2,32,400 Milkfish 720 kg Rs 28,800	As above Rs 48,400	Rs 2,12,800 (138 days)
Fattening 0.3 ha	Crabs 560 kg Rs 1,22,850	As above Rs 56,200	Rs 66,650 (30 days)

Total production in all 14 ponds of 5.2 ha	=	6340 kg
Postharvest mortality 3.8%	=	240 kg
Total Income	=	Rs 12,20,000
Expenditure	=	Rs 3,05,000
Net profit	=	Rs 9,15,000
Period of culture	=	4 months
Average net income	=	Rs 1,75,961/ ha/4 months

Table 22. Achievements of CMFRI in breeding and seed production of crabs

Species	Year of work & Authors	Results
Mud crab *Scylla serrata*	1983 Marichamy & Rajapackiam (1984)	Incubation period, egg hatching and complete metamorphosis studied for the first time in India
- do -	1983-84 Marichamy & Rajapackiam (1992)	Egg hatching and early development upto crab stage studied under controlled conditions at Tuticorin. A maximum of 15% survival at crab stage obtained.
Scylla tranque-barica & S. serrata	1994-95 M.K. Anil (Personal communication)	Complete larval development of both species studied for the first time in India. Experimental seed production trials yielded 20 to 25% survival for both species.
Swimming crab *Portunus pelagicus*	1996 Josileen and others (1996)	Larval rearing and seed production successfully carried out at Mandapam with a survival rate of 80 to 85% upto zoea-V stage and lesser survival rates for successive stages.

the marine as well as brackishwater environments. In India, both the species (*Scylla serrata and S. tranquebarica*) coexist in the inshore sea, estuaries, backwaters, coastal lakes and mangrove swamps of all maritime States on the mainland and the creeks and bays of Andaman and Nicobar Islands. They prefer muddy or sandy bottom.

Mudcrab fattening experiments using *Scylla tranquebarica* were carried out at Narakkal in a pond of 1000 sq.m at a low stocking density of 300 water crabs, each of 500 to 550 g during 1996. They were fed daily with salted trash fish at 10% of body weight. Water exchange was facilitated by means of tidal flow. Selective harvesting of mud crabs was carried out at weekly intervals, after 21 days of the initiation of the experiment. A total of Rs 8500/- was spent towards the cost of crab and the feed. The harvested crabs were sold for a sum of Rs 9600/- in 40 days (Table 21). The experiment is being continued. Crab fattening has to be pursued for a minimum of 7 to 8 months with continuous harvesting and stocking to make it an economically viable

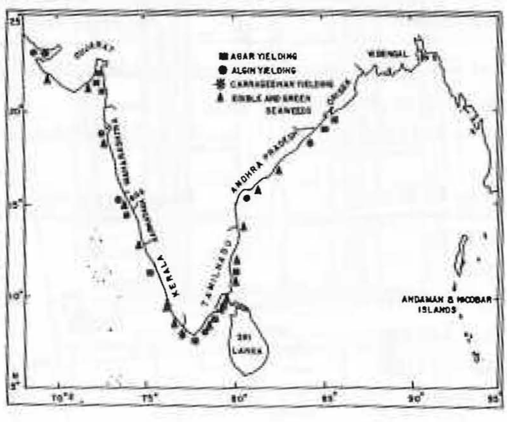


Fig.20. Distribution and abundance of various seaweed resources along the Indian coastline.

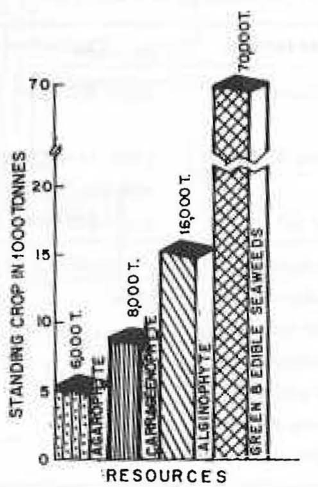


Fig.21. Standard crop of seaweed resources along the Indian coast

operation. Profitability can be further increased by polyculture with compatible species of fish and shellfish.

Experiments conducted at the CMFRI, Tuticorin during 1983-85 on the mud crabs *Scylla serrata* and *S. tranquebarica* gave encouraging results. A survival of 15% was achieved from the egg to the first instar stage. The techniques have been further refined as a result of which a survival of 20% has been achieved recently. Similar experiments conducted in the CMFRI, Cochin on both these species also gave 20% survival rate. Experiments currently being carried out at Mandapam gave encouraging results and an economically viable hatchery technology is emerging from these efforts.

The CMFRI has carried out breeding of the marine crab *Portunus pelagicus* and succeeded in obtaining a survival of 8 to 10% from the egg to the first instar stage. Experiments are being continued to increase the survival rate and develop a viable hatchery technology for this species. Experiments on the broodstock development and farming revealed that this species has great potential for seafarming. Three generations of *P.pelagicus* have been produced successively and being successfully maintained in the CMFRI Mandapam marine hatchery (Table 22).

Studies on the farming of mud crabs have been initiated by the Institute as early as 1983 and being perfected over the years. Recently three types of farming have been undertaken, namely, monoculture, polyculture and fattening. Depending on the availability of seed, these technologies can be advantageously made use of by the entrepreneurs. Table 21 deals with the economics of these three methods of farming.

One of the major constraints being faced by the farmers is the inadequate supply of seed crabs, as the only source at present is the wild stock in most of the countries, where crab farming is attempted. It is, therefore, imperative that concerted effort is made to develop commercial hatcheries for adequate and sustained supply of baby crabs to make mud crab farming an organised industry. The first commercial mud crab hatchery established by Indo Marine Aquaculture (located at Marthanpattinam, Thennampattinam - 609 115, Sirkali Taluk, Nagapattinam district, Tamil Nadu) has come into production and sale of seed in January, 1996.

8.8 Seaweed culture

About 700 species of marine algae have been recorded from different parts of the Indian coast. Of these, nearly 60 species are commercially important, belonging to green, brown and red algae which occur along the southeast coast, Tamil Nadu, Gujarat, Lakshadweep and Andaman & Nicobar Islands. Fairly rich seaweed beds are

Table 23. Important Indian seaweeds and their standing crop

Agarophytes	Alginophytes	Carrageenophytes	Edible & green seaweeds
Gracilaria edulis	*Sargassum* spp.	*Hypnea valentiae*	*Ulva* sp.
G. corticata	*Turbinaria* spp.	*H. musciforms*	*Enteromorpha*
G. crassa	*Hormophysa* sp.	*Eucheuma* sp.	*Caulerpa* spp.
G. follifera	*Cystosiera* sp.		*Codium* spp.
G. verrucosa			*Laurencia* spp.
Gelidiella acerosa			*Acanthophora*
Gelidium sp.			
Standing crop (in tonnes)			
6,000	16,000	8,000	70,000
			Total 100,000

Table 24. Methods of seaweed cultivation

Fragment Culture Methods	Spore Culture Methods
1. Coir rope longline	1. Settling spores on coral stones
2. Coir rope net	2. On gastropod shells
3. Nylon rope	3. Nylon rope
4. Broadcasting in ponds	4. Coir rope
5. Tying in plastic bags	5. Nylon twine
6. Tying on floating rafts	6. Circular cement blocks
7. Tying the fragments to rocks	

Current Production of Phycocolloids from Seaweed (in tonnes)

Colloids	Global	India	No. of Indian Factories
1. Agar	5000 (from 30,000t dry wt)	130 (from 750t dry wt)	30
2. Algin	-	500 (from 3000t dry wt)	28
3. Carrageenan	-	Nil	Nil

present in the vicinity of Bombay, Karwar, Ratnagiri, Goa, Varkala, Kadalundi, Vizhinjam, Visakhapatnam and in the coastal lakes of Ashtamudi, Pulicat and Chilka (Fig. 20).

As per the current estimate, the total standing crop of all seaweeds in the Indian waters is more than one hundred thousand tonnes (wet wt) consisting of 6,000 tonnes of agar yielding red seaweeds, 16,000 tonnes of algin yielding seaweeds and the remaining quantity is of edible and carrageenan yielding seaweeds (Fig. 21). The important species are listed in Table 23. Seaweeds are cultured either by vegetative propagation using fragments of seaweeds collected from the natural beds or by spores such as tetraspores or carpospores. The fragments are also cultured by broadcasting them in outdoor ponds and tanks (Table 24).

Seaweed farming along the coast of peninsular India has the potential to fetch a return of Rs. 9,000/- per ha per year for an investment of Rs. 36,000/-, assuming the production rate to be 3 fold in each of the two crops/harvests. A production target of 2 million metric tonnes of cultivated seaweeds is proposed to be achieved by 2020 (Figs 22 & 23). The hike in the production from the current 0.2 million tonnes through wild harvest to 2 million tonnes by farming by 2020 is possible through the following activities:

1) enlargement of the farming areas including the brackishwater lakes
2) upgradation of culture technology into intensive culture and multispecies culture systems
3) onshore culture in tanks, ponds and raceways
4) introduction of high yielding, exotic species and development of high yielding varieties through genetic manipulations

8.9. Seacucumber culture

There are more than 200 species of seacucumber in the seas around India, of which 75 species are distributed in the shallow water. They occur mainly in the Gulf of Mannar and Palk Bay, the Andaman and Nicobar Islands and the Lakshadweep. In the Gulf of Mannar and Palk Bay *Holothuria scabra* is the most important species for processing in to beche-de-mer. In recent years Actinopyga echinites and *A. miliaris* are also exploited in good quantities. *Holothuria spinifera* and *Bohadschia marmorata* are available in smaller quantities only. Although *Holothuria scabra* and *H. spinifera* are not found in the Lakshadweep, Holothuria nobilis and *Thelenta ananas* are quite important in this island, where *Bohadschia marmorata, Actinopyga mauritiana, A. echinites, A. miliaris, Stichopus variegatus, S. chloronotus* and *Holothuria atra* are also available to some extent. While the most important species in the Andaman and Nicobar Islands is *H. scabra, smaller quantities of Holothuria atra, A. mauritiana, A. echinites, A. miliaris, H. nobilis, Stichopus variegatus* and

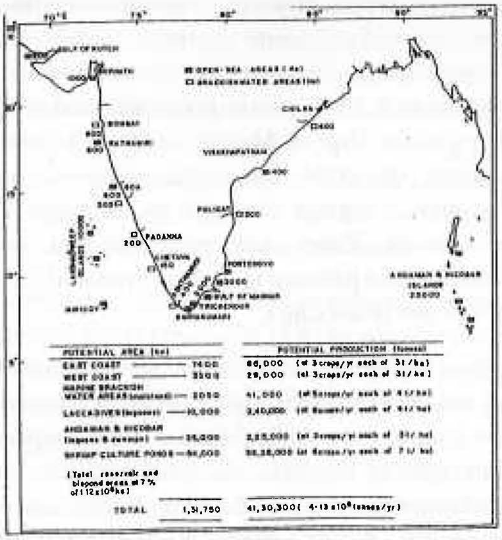


Fig.22. Potential areas of seaweed aquaculture along the Indian EEZ

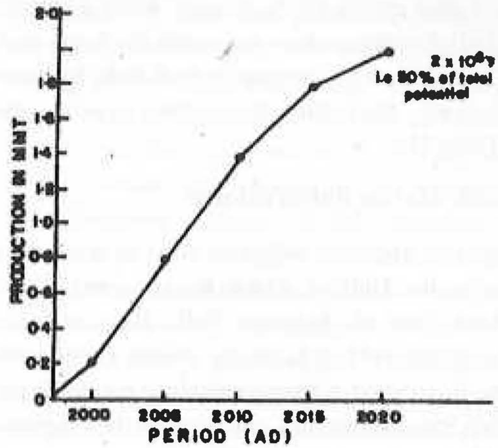


Fig.23. Projected Indian marciulture production of seaweeds

S. chloronotus also occur, but *H. spinifera* is absent in this island. The record of *Thelenota ananas* from the Andamans needs to be checked. Sea- cucumbers are distributed in the Gulf of Kutch and in certain other locations along the coast of the mainland of India, but they are not of commercial value.

The CMFRI succeeded in the production seed of *H.scabra* for the first time in 1988 by induced breeding through thermal stimulation at the Tuticorin field mariculture laboratory. (James *et al.*, 1989). Since then *H. scabra* seed is being produced in this hatchery on a regular basis.

Beche-de-mer production is a very ancient industry in India. The Chinese had constant trade with southern India for more than thousand years. Customs records on the export of *Beche-de-mer* from the Madras Presidency are available from 1898 onwards. Since the middle of the last century a good *Beche-de-mer* processing industry was functioning in the Lakshadweep, but it ceased in recent times. In the Andamans also there was good processing activity since the mid seventies around Port Blair, but it stopped recently due to the ban imposed by the Andaman and Nicobar Administration.

Table 25. Annual export of beche-de-mer from India (Q = Quantity in kg V = Value in Rs.)

Country		1990	1991	1992	1993	1994
Taiwan	Q	-	-	255	-	-
	V	-	-	3,19,038	-	-
Hongkong	Q	-	984	20,520	13,020	37,562
	V	-	1,32,645	18,02,625	10,96,992	65,18,207
Singapore	Q	37,338	27,962	18,566	6,657	8,254
	V	50,90,987	85,02,083	54,68,454	25,76,362	25,86,972
Total	Q	37,388	28,946	39,341	19,677	45,816
	V	50,90,987	86,34,728	75,90,117	36,73,354	91,05,179

All countries which produce *Beche-de-mer* do not consume. Some of the countries consume, export and also import *Beche-de-mer*, while countries like India only produce and export *Beche-de-mer*. The export of *Beche-de-mer* from India has been showing fluctuating trends from year to year (Table 25).

8.10. Marine finfish culture

India is endowed with vast areas of coral reefs along the Gulf of Kutch, Kerala coast, Wadge Bank, Gulf of Mannar, Palk Bay and the Andaman and Lakshadweep islands. Coral reefs are distributed: (i) in the nearshore regions in the Palk Bay and the Gulf of Mannar and the lagoons of Lakshadweep islands, (ii) in depths of over 400 m along the west coast, and (iii) around the islands in the Andaman and Lakshadweep. Most of these areas are not suitable for fishing with trawls or gillnets. However traps and longlines are operated efficiently in these areas. The present fishery, however, is restricted to trawls and hooks & lines in the inshore waters and perch traps in the Gulf of Mannar and Palk Bay. Among the coral fishes, the groupers, red snappers, pigface breams and a range of ornamental fishes are most abundant, and indicate good potential for culture in coastal farm ponds and in net cages.

About 40 species of groupers, similar number of red snappers and 9 species of pigface breams are known from India. Among the groupers, *Epinephelus tauvina, E. malabaricus, E. undulosus, E. areolatus, E. merra, E. fasciatus, E. sonnerati, E. bleekeri, E. diacanthus, E. chlorostigma, E. caeruleopunctatus* and *Promicrops lanceolatus* constitute important

Table 26. Marine fish culture experiments carried out in India

Place	Culture System	Culture Methods	Species rate(mm)	Growth (%)	Survival (Kg/ha/yr)	Production	Authors
Krusadi	Monoculture	Pond	*C. chanos*	230-240/yr	–	–	Chacko and Mahadevan (1956)
	Monoculture	Pond	*C. chanos*	240-250/yr	–	–	Menon (1959)
Mandapam	Monoculture	Pond	*C. chanos*	300 /yr	9-11	212-455	Tampi (1960)
Veppalodai	Polyculture	Pond	*C. chanos*	333 /yr	50	192	Marichamy and Rajapackiam (1982)
Tuticorin	Polyculture	Pond	*C. chanos*	300-378/yr	5	324	Marichamy (1980)
			L. macrolepis	211-240/yr	67	630	
			S. serrata	130-175/yr	26	690	
Mandapam	Monoculture	Tank	*A. bicolor bicolor*	23/month	98	2.2 kg/sqm / 5 months	Dorairaj *et.al* (1985)
Mandapam	Monoculture	Cage	*S.canaliculatus*	8.5/month		-	James *et.al* (1985b)
			S. javus	6.2/month	60	-	
			E. tauvina	19/month	73	-	
			S. sihama	10/month	- -		
Mandapam	Polyculture	Pond	*V. seheli*	15.8-24.6/month	-	-	James *et.al* (1985a)
			L.macrolepis	13/month	-	-	
				C. chanos	16.8-30/month	-	
			P. indicus	9.4/month	-	-	
			S. sihama	11.4/month	-	-	
Mandapam	Polyculture	Pen	*Mugil sp.*	18/month	-	-	Venkataraman *et.al* (1985)
			C. chanos	50/month			
Tuticorin	Polyculture	Pen	*C. chanos*	27/month	5-48	damaged	Shanmugam and Bensam (1982)
Tuticorin	Monoculture	Pond	*C. chanos*	44/month		318-857	Bensam and Marichamy (1982)
Mandapam	Monoculture	Cage	*E. tauvina*	16.3mm/month	-	-	Hamsa and Kasim (1992)

fisheries. The red snappers of commercial importance include *Lutjanus rivulatus*, *L. malabaricus*, *L. fulviflamma*, *L. kasmira*, *L. argentimaculatus*, *L. waigiensis*, *L. lineolatus*, *L. gibbus* and *Pristipomoides typus*. Among the pigface breams, *Lethrinus nebulosus*, *L. lentjan*, *L. miniatus*, *L. elongatus* and *L. mahsenoides* are most abundant in the landings.

During the 1985-94 period, an estimated average annual perch landing of 13,616 t was obtained in India with groupers forming 44.9%, pigface breams 31.1% and snappers 24.0%. Almost the entire catch was taken from the grounds in the 0 to 50 m depth. The potential of these fishes in the Indian EEZ is estimated to be around 40,000 t in the 0 to 50 m depth zone and 14,600 t in the 50 to 300 m depth zone. The wide difference between the potential and the landings is due to the grounds not being accessible to trawlers and setnets. Therefore, fishing by traps and longlines needs to be introduced for the effective exploitation of these resources.

The coral reefs constitute an important habitat for a vast range of ornamental fishes of about 300 species. Of these, fishes of the families Acanthuridae, Pomacentridae, Labridae, Scaridae, Chaetodontidae, Siganidae, Holocentridae, Syngnathidae and Balistidae are important. These fishes are known to be abundant mainly in the lagoons of the Lakshadweep islands, followed by the Andamans, Gulf of Mannar, Palk Bay and Vizhinjam Bay. Currently, there is no exploitation of these fishes for aquarium purpose. The CMFRI has initiated a detailed survey and assessment of the ornamental fishes of the Lakshadweep.

In the area of marine fish culture, India is still in the experimental phase. Experiments on several species : *Chanos chanos*, *Mugil cephalus*, *Liza macrolepis*, *Valamugil seheli*, *Siganus canaliculatus*, *S. javus*, *Sillago sihama*, *Epinephelus tauvina*, *Anguilla bicolor bicolor*, *Lates calcarifer* and *Etroplus suratensis* were conducted (Table 26). Breeding and hatchery production of seed and growout technologies are yet to be developed. Very recently lucrative nursery grounds of grouper seed (of 60 to 260 mm size) were located along the Gulf of Mannar coast and live juveniles of *E. tauvina* and *E. malabaricus* are exported live to Hongkong and Singapore. About 15,000 juveniles are collected per month from one coastal nursery ground near Tuticorin for this purpose, with peak collection in January and February. The CMFRI has embarked on a programme of breeding and hatchery production of seed of groupers, snappers and breams. At the Tuticorin farm of the CMFRI, 300 juveniles of E. tauvina of 65 to 285 mm length range (mean 130 mm and 80 g) were stocked during June-July 1996. By the end of September 1996 (75 days) the groupers at Tuticorin attained an average size of 225 mm and 110 g. At the Mandapam centre of the CMFRI *E. tauvina* of the length range of 92 to 245 mm and weight range of 10 to 200 g were stocked in outdoor cement tanks and fed sardines at the rate of 10% body weight. In six months, they attained 180 to 360 mm and 160 to 630 g. Eyeball swelling, tailrot and infection by *Caligus* resulted in some mortality. Recently ovaprim was injected to *E. tauvina* at the rate of 0.5 ml per kg body weight; in six days, spawning took place in fish of 2.0 to 2.5 kg wt. A private company (Sannet Aqua) is currently operating a net cage at Tuticorin in the Gulf of Mannar at a depth of 4m for captive holding and fattening of groupers (fed on sardines) for live export in ships to Hongkong. The comnpany has exported in 1996 about 20 tonnes of live groupers.

9. Stock enhancement programme

9.1. Searanching

Searanching is termed as production and release of aquatic organisms into their natural habitats to augment their stock. It was in the United States that the idea of searanching originated as back as

Table 27. Some searanching results: global & Indian experience

Country	Location	Species	No.of seed ranched	Year	Results
1. Japan	Komance-Ko-Lagoon	Kuruma shrimp	700 million	-	2.4 times increase in the production of kuruma shrimp
	-do-	Seabream Flounder	16 million 19 million	-	Substantial increase in the wild stock
	16 national and 43 local aqua-culture centres	80 coastal species	-	-	-
2. U.S.A.	Hawaii	Striped mullets	Pilot scale	1970s	100% increase in the wild stock
	Texas	Red drum	Pilot scale	1970s	Significant increase
	Hawaii	Threadfin	Pilot scale	1970s	Significant increase
3. -	Bohai sea Yellow sea	Penaeid shrimps	Large scale	1980s	Recapture rate4 to 13.6%: searanched seed account for > 90% of catch
4. India (CMFRI)	Palk Bay	*Penaeus semisulcatus*	6 million	1990-94	Augmentated yield
	Gulf of Mannar (Pearl banks)	*Pinctada fucata*	10 million	1985 & 1990	Significant increase in adult pearl oyster in the natural beds
	Ashtamudi estuarine lake in Kerala	Clams	0.486 million	1993-96	Fairly good increase in production

1870. Since then many countries have been practising this for enhancing the resources as fishing pressure is evidently felt on many of the resources. Searanching also helps in conserving the resources. The idea of searanching in India started with pearl oyster which appeared to diminish in number since the Gulf of Mannar pearl fishery of 1961 due to many factors. To overcome the erratic natural population of pearl oysters, it was felt that searanching would be the correct step. With the establishment of a molluscan hatchery at Tuticorin and large scale production of seed, searanching became a reality. Ranching of shrimp seed has become relevant in the context of diminishing returns from the natural resources. The spiny lobsters, clams and seacucumbers offer immense scope for searanching because of the increasing demand in the export trade, decreasing production from the fishery, and the success in hatchery production of their seed (Table 27).

Japan is the pioneer in the searanching of a variety of marine organisms including shellfishes and finfishes. They embarked on a stock enhancement programme (SEP) in a big way involving 16 national and 43 local aquaculture centres, focussing on the problems of 80 coastal species including the kuruma prawn *(Penaeus japonicus)*, blue crab, red seabream (*Pagrus major)*, abalone and flatfish. By releasing about 700 million seed of *P. japonicus* in the Komance-Ko-lagoon, they have increased the production by 2.4 times. In the case of finfishes, ranching of 16 million seabreams and 19 million flounders resulted in substantially supplementing the natural stock.

In Hawaii, stock enhancement programme was undertaken for the depleted coastal fisheries, of which the two highest ranked species, the Pacific threadfin *(Polydactylus sexfilis)* and the striped mullet (*Mugil cephalus*) were taken up in the first phase as test species. Pilot hatchery release experiments resulted in 100% increase in mullet abundance in the nursery habitat. In Texas, consequent on the decline of the red drum

Table 28. Proposed pilot scale searanching programme by CMFRI under the 9th Five Year Plan

Commodity	Location	Quantity (million)	Species
Shrimps	Veraval	10.0	*Penaeus penicillatus, Penaeus merguiensis*
	Karwar	5.0	*P. merguiensis, Parapenaeopsis stylifera*
	Calicut	10.0	*Metapenaeus dobsoni, P.indicus P. stylifera*
	Vizhinjam	15.0	*P.indicus, Metapenaeus dobsoni P. stylifera*
	Mandapam	10.0	*P. semisulcatus*
	Madras	10.0	*P. indicus, P. monodon*
	Visakhapatnam	10.0	*P. indicus, P. monodon*
Lobsters	Veraval	0.2	*Panulirus polyphagus, Thenus orientalis*
	Calicut	0.2	*P. homarus*
	Vizhinjam	0.2	*P. homarus, T. orientalis*
	Mandapam	0.2	*P. homarus, P. ornatus*
	Madras	0.2	*P. homarus, T. orientalis*
Pearl	Veraval	12.0	*Pinctada fucata oyster*
	Vizhinjam	6.0	*P. fucata*
	Mandapam	12.0	*P. fucata*
Cephalopod	Veraval	1.0	*Sepia pharaonis, Loligo duvaucelli*
	Calicut	1.0	*S. pharaonis, L. duvaucelli*

(Sciaenops ocellatus) fishery during the 1970s, a stock enhancement programme was started to recover the resource by the Texas Parks and Wild Life Department. Studies so far conducted revealed that the stocked fish survived in significant numbers and thereby enhanced the natural populations. Stocking hatchery fish along with stringent fishery and habitat protection measures could revive the red bream population substantially.

Stock enhancement programmes on penaeid shrimps began in the mid '80s along the coasts of the Bohai Sea and the central and northern Yellow Sea to build up the collapsed stocks in the traditional fishing grounds. A remarkable recapture rate ranging from 4.0 to 13.6% was observed under these programmes. At present the released shrimp accounts for more than 90% of the total catch.

In India, the CMFRI carried out preliminary ranching experiments on *Penaeus semisulcatus* in the Palk Bay at Mandapam, clams in the Ashtamudi lake and pearl oysters and seacucumber in the Gulf of Mannar with encouraging results. 6 million postlarvae (PL- 15 to 32) of *P.semisulcatus* produced in the pilot prawn hatchery at Mandapam, Tamil Nadu were searanched in the Palk Bay from 1990 onwards. This programme helped in augmenting the production of *P.semisulcatus* in the coastal waters of Palk Bay. The PL - 15 were reared to a size of over 60 mm in length. A total of 2964 laboratory reared and farm grown *P. semisulcatus* of 60 to 110 mm size were tagged and released into the Palk Bay. One percent of these shrimps were obtained from the commercial trawl catches landed in two nearby landing centres within a period of 53 days. During this period, the tagged prawns have migrated to a distance of 30 to 35 km. The above experiments show that the searanched postlarvae of P. semisulcatus survive, migrate, grow and get recruited into the fishery in Palk Bay (Pillai, et al., 1991). A total of 10 million pearl oyster spat (0.9 to 11.3 mm size; average 1.53 to 5.7 mm) was searanched in the Gulf of Mannar in 3 pearl oyster beds (paars) in 17 batches during 1985 and 1990 and 0.486 million clam spat ranched in Ashtamudi lake, Kerala State in 7 batches during 1993-96 as detailed here. The first batch of 64,000 seed of *Paphia malabarica* measuring 12.4 mm average length were ranched in Ashtamudi lake (Dalavapuram) on 18.2.93 in a 25 m^2 area in 1 m depth and the site was fenced with 3.0 mm netlon screen. On 19.3.93 they measured 20.4 mm and by 3.5.93 they grew to 30.3 mm. In the same area a total of 30,000 seed of *P.malabarica* measuring 4.9 mm length were reared in cages as their size was small for planting in the field. By 3.5.93 they attained 12.2 mm and were ranched in the same area. These seed were covered with 1 cm mesh synthetic net to protect them from predators. At Munambam *P.malabarica* occurs rarely. Hence a consignment of 8500 seed was ranched in a 10 m^2 area on 19.2.93 in 0.5 m depth. The clam seed measured 12.4 mm and they were covered with 1 cm mesh synthetic net. By the end of April they attained 23.4 mm length.

Taking into account the declining status of some of our prime fisheries, their high economic value and the prospects of overexploitation of the wild stocks, the following species are proposed for pilot-scale searanching for stock enhancement at different centres along the Indian coast by the CMFRI under the 9th Five Year Plan (Table 28). Besides, under the Indian-Australian Cooperation in S&T, searanching has been proposed for stock enhancement in the Vizhinjam bay and the contiguous waters (Table 29).

Table 29. Proposed searanching programme for the Vizhinjam bay and the contiguous Gulf of Mannar- Wadge Bank -Minicoy lagoon - Cochin coast under the New Horizon India - Australia cooperation in Science & Technology

Location	Species	No. of seed to be ranched in 5 years (in million)
1. Vizhinjam	(i) Shrimp (*P.stylifera, M.dobsoni, P.indicus*)	8
	(ii) Pearl oyster (*P.fucata*)	160
	(iii) Grouper (*E.tauvina*)	16
2. Mandapam	(i) Shrimp (*P.indicus, P.semisulcatus*)	24
	(ii) Pearl oyster (*P.fucata*)	160
	(iii) Seacucumber (*H.scabra*)	10
	(iv) Grouper (*E.tauvina*)	18
3. Tuticorin	(i) Shrimp (*P.indicus, P.semisulcatus*)	36
	(ii) Pearl oyster (*P.fucata*)	180
	(iii) Seacucumber (*H.scabra*)	8
	(iv) Grouper (*E.tauvina*)	16
4. Quilon	(i) Shrimp (*P.stylifera, M.dobsoni, P.indicus*)	330
5. Alleppey	(i) Shrimp (*P.stylifera, M.dobsoni, P.indicus*)	172
6. Cochin	(i) Shrimp (*P.stylifera, M.dobsoni, P.indicus*)	330
7. Minicoy	(i) Pearl oyster (*P.fucata*)	20
	(ii) Seacucumber (*H.scabra*)	2

Total: Shrimp = 900 ; Pearl oyster = 520 ; Sea cucumber = 20 ; Grouper = 50

All Total = 1490

9.2 Artificial fish habitats

A significant number of maritime nations are showing increasing interest in artificial aquatic habitat enhancement programmes and about 40 countries in six continents have established such habitats to promote capture fisheries productivity and production (Robert and Choule, 1983).

The major objective of developing artificial reef habitats is basically to improve the conventional, commercial and recreational fishing and to sustain marine productivity. A variety of structures are used to attract various species of marine organisms. They range from improvement to the indigenous structures spread in extensive areas to very sophisticated concrete structures. Artificial fish habitats are being used at present to increase tuna catches in the tropical Pacific, to augment demersal fish catches in the Southeast Asian waters, to provide recreational fishing in the USA and to culture shellfish in European waters. Artificial reefs are in use over the last decade close to artisanal fishing villages along the districts of Thiruvananthapuram in Kerala and Kanyakumari and Chengalput districts in Tamil Nadu. Work on efficient design and fabrication of artificial reefs has been carried out by (i) the Fisheries Cell of the Programme for Community Development, Thiruvananthapuram, (ii) the South

Table 30. Species composition in artificial reefs in the Thiruvananthapuram and Kanyakumari district coasts

Local Name	Species	Qty in % in the total number of fish
Uralupara	***Atule mate***	41.20%
Kannan Pola/	***Priacanthus cruentatus***	12.80%
Perumkanny	***Priacanthus haamrur***	
Ayala	***Rastrelliger kanagurta***	10.30%
Clathy	***Abalistes stellatus***	6.50%
	Odonus niger	
Vala Mural	***Ablennes hians***	3.00%
Kurali	***Lethrinus nebulosus***	2.70%
Kozhiyala	***Decapterus russelli***	2.50%
Kozhuva Para	***Carangoides*** **sp.**	2.40%
Chakani Para	***Carangoides*** **sp.**	2.40%
Pola	*Lutjanus lutjanus*	2.10%
Para	***Carangoides*** **sp.**	1.80%
Kozhuva	***Carangoides gymnostethus***	1.40%
Vela Para	***Carangoides*** **sp.**	1.20%
Kottan Para	***Carangoides*** **sp.**	1.10%
Vangada	***Megalaspis cordyla***	1.00%
Komali Para	***Carangoides*** **sp.**	1.00%
Kallu Kanava	***Sepia pharaonis***	0.60%
Others		6.00%
Total number of fish		2,632

(Species less than 1% in numbers are included under 'others' except cuttlefish)

Source: Artificial fish habitats, D'Cruz (1995).

Indian Federation of Fishermen, Thiruvananthapuram, (iii) The Waves, Madras and (iv) the Centre for Research on New International Economic Order, Madras.

D'Cruz (1995) observed that the setting up of artificial habitats for fisheries in the vicinity of the villages along the Kanyakumari-Thiruvananthapuram coasts enabled the fishermen to establish local fisheries for the low skilled and aged fishermen on regular basis and for the skilled fishermen on occasional basis during the better catching season of AFH's. It indicates that the prime objective of the construction of AFH's is to create convenient and rewarding fishing grounds by establishing local fisheries, especially during the lean fishing season (December to March). He further showed that the rainy season (southwest monsoon) and the fair weather season (December to February) are the two lean seasons creating difficulties to the fishermen of Thiruvananthapuram coast. According to the fishermen, though there is better availability of fish in the sea during the monsoon, the heavy rains and the surf during this season result in lower catches. In the fair weather season, little or no fish is available in the shallow waters due to the crystal clear nonturbid seawater. He also observed that in the FAD's half of the total species was contributed by Priacanthus' sp. (49.72%) and about a quarter was contributed by *Sepia pharaonis*. Eventhough *Priacanthus* sp. dominated in terms of number, a *Sepia sp.* contributed much higher share in terms of weight. Compared to the AR's, FAD's gave better daily income due to the dominance of the high

Table 31. Species composition in fish aggregating devices in the Thiruvananthapuram and Kanyakumari district coasts

Local Name	**Species**	**Qty in % in the total number of fish**
Kannan Pola	*Priacanthus cruentatus*	49.70%
	Priacanthus hamrur	
Kallu Kanava	*Sepia pharaonis*	23.40%
Uralupara	*Atule mate*	8.30%
Ayala	*Rastrelliger kanagurta*	4.40%
Clathy	*Abalistes stellatus*	2.80%
	Odonus niger	
Mural	*Dussumieria acuta*	1.80%
Vangada	*Megalaspis cordyla*	1.20%
Kozhiyala	*Decapterus russelli*	1.10%
	Decapterus macrosoma	
Others	—	7.30%
Total number of fish		15,419

(Species less than 1% in numbers are included as others)

Source: Artificial fish habitats, D'Cruz (1995).

value cuttlefish and squids (Tables 30 & 31).

It has been observed that since the AFH's have a significant impact on the fisheries of the artisanal fishing communities, they should be encouraged on a large scale with the participation of the community in selected villages for the benefit of the nonmotorised fishermen who possess only limited access to the resources.

10. Conclusion

Mariculture provides good opportunities for : (1) seafarming and associated activities of stock enhancement through searanching and artificial fish habitats, (2) land-based saline aquaculture in coastal zones using pump-fed or tide-fed seawater or brackishwater, and (3) hinterland aquaculture in saline soil and saline aquifer ecosystems. While coastal land-based shrimp aquaculture has grown rapidly in the current decade, the 1994-95 crop failures due to diseases have forced the industry to adopt ecofriendly systems of farming. The new approach is essentially of: (1) closed systems of farming coupled with the application of biotechnological, bacterial products; and (2) integration of compatible candidate species of bivalves, fishes, seacucumbers and seaweeds in the farming systems. The current practices have the potential to make coastal aquaculture more sustainable from the biological, ecological, legal, social and economic points of view. As a result of the adoption of these packages of practices the industry is set to quickly revive and yield over one lakh tonnes of shrimps during 1996 as against about 75,000 tonnes during 1995. There is, however, considerable fear of the outcome of the Supreme Court case against coastal aquaculture, which depends critically on access to the seafront. Seafarming in the opensea and the contiguous more protected bays, coves, gulfs, lakes, backwaters, lagoons and estuaries, inspite of the good potential, remain dormant in India mainly because of lack of awareness, issues of ownership of sites, opposition from traditional fishermen and risks from natural calamities. However, considerable R & D efforts have been initiated and private farms are being established in the Kerala backwaters (for bivalves and seaweeds) and also in the opensea in Tamil Nadu (for groupers and bivalves) and Kerala (for bivalves). Artificial fish habitat construction and operation by the small scale fishermen in the inshore fishing grounds has become a success in parts of Kerala and Tamil Nadu and is set to take off in Maharashtra, Andhra Pradesh and Orissa. There is considerable scope for the expansion of the artificial fish habitat programme in all the maritime states where it has substantial potential to become an industry as in Korea. The Indian experience of one percent of searanched banana shrimp entering the commercial catch from Palk Bay from a mere ranching of 10 million seed over a period of 5 years and the Bohoi Sea & Yellow Sea experience of about 96% of searanched shrimp entering the commercial catch from a massive stocking programme suggest that the shrimp stocks in the Indian seas, particularly the gulfs (Gulf of Kutch, Cambay and Mannar), bays (Bays of Vizhinjam, Palk, Kakinada and Waltair) the open Sandheads off West Bengal and the mudbanks of Kerala could be fast revived and made very productive by searanching. With an annual 8 billion shrimp seed capacity in about 170 hatcheries located along the coasts of the maritime states and with only less than half this quantity required for current farming, the surplus seed could be used for searanching. The resource for this purpose could be drawn from a portion of the present one percent cess on marine products export. The government of India may consider this question and issue the necessary guidelines for the implementation of this programme. Purchase of seed at a prefixed rate by the government may also serve as a support price in times of slump in price. Simultaneously, finfish, bivalves, abalones and seacucumbers also need to be taken up for searanching.

The hinterland saline soil aquifer ecosystems are now known to have the potential to produce at the rate of 2 to 3 tonnes of shrimps or marine fish per hectare in single crops of about 6 months. With about 8.5 million ha of inland saline ecosystem, the country has vast scope for progressively expanding this activity to commerical scales. There is need to accelerate the R & D in this regard by involving the State Departments of fisheries and agriculture, universities, NGO's, cooperatives, farmers' association and entrepreuners.

References

Appukuttan K.K. and Muthaiah, P.,1996. Technology of edible oyster culture. *Bull. Cent. Mar. Fish. Res. Inst.*, 48: 64-69.

D'Cruz, Titto., 1995. Artificial fish habitats - impacts on artisanal fisheries. *Publ. South Indian Federation of Fishermen Societies, Trivandrum*, pp. 57

Dorairaj, K., Soundarajan, R. and Kandaswami, D., 1985. Experimental culture of the short-finned eel *Anguilla bicolor bicolor* Mc Chelland. *Proc. Symp. Coastal Aquaculture*, 3: 883-891., Mar. Bio. Ass. India, 12-18 Jan., 1980

Hamsa, K.M.S.A. and Mohammed Kasim H.,1992. Growth and production potential of young grouper *Epinephalus tauvina* (forskal) reared in fixed net cages., *J. Mar. Bio. Ass. India*, 34(1 & 2): 271-276

Imre Csavas, 1995. "Status and outlook of World Aquaculture" - Paper presented at the Symposium on Sustainable Aquaculture.

James, D.B., Rajapandian, M.E., Baskar, B.K. and Gopinathan, C.P., 1989. Successful induced spawning and rearing of the holothurian *Holothuria (Metriatyla) scabra* Jaeger at Tuticorin. *Mar. Fish. Infor. Serv. T&E Ser.*, 87: 30-33.

James, P.S.B.R., Mohanraj, G., Rengaswamy, V.S. and Raju, A.,1985. Preliminary experiments on the culture of grey mullets at Mandapam. Proc. *Symp. Coastal Aquaculture*, 3: 791-796. Mar. Bio. Ass. India, Cochin 12-18 Jan., 1980

James, P.S.B.R. Soundarajan, R. and Joseph Xavier Rodrigo, 1985. Preliminary culture of fin-fishes in cages in the coastal waters of Palk Bay at Mandapam. *Proc. Symp. Coastal Aquaculture*, 3: 910-915., Mar- Bio. Ass. India, 12-18 Jan., 1980

Josileen Jose, Arputharaj, M.R. Ramakrishnan, A. and Viramani, A., 1996. Larval rearing of the crab *Portunus pelagicus* (Crustacea, Portunidae) in hatchery at Mandapam Regional Centre of CMFRI. *Mar. Fish. Infor. Serv. T&E Ser.*, 143: 23- 24.

Kuriakose, P.S. and Appukuttan, K.K., 1996. Technology of mussel culture. *Bull. Cent. Mar. Fish. Res. Inst.*, 48: 70-75.

Marichamy, R. and Rajapackiam, S., 1984. Culture of larvae of *Scylla serrata*. *Mar. Fish. Infor. Serv. T&E Ser.*, 58: 13- 15.

Marichamy, R. and Rajapackiam, S., 1992. Experiments on larval rearing and seed production of mud crab, *Scylla serrata*. *Proc. of Seminar on Mud Crab Culture*, Bay of Bengal Programme Rep., 51: 135-141.

Ministry of Agriculture, 1992. Guidelines for Sustainable Development and Management of Brackishwater Aquaculture.

Moriarity, D.J.W., 1996. Microbial biotechnology: a key ingredient for sustainable aquaculture. *INFOFISH International*, No. 4/96 July/ August 1996: 29-33.

Narasimham, K.A. and Lamxilatha, P., 1996. Clam culture. *Bull. Cent. Mar. Fish. Res. Inst.*, 48: 76-87.

NEW, M.B. 1996. Responsible use of aquaculture feeds. *Aquaculture Asia*, 1(1): 3-15.

Pillai, N.N., Radhakrishnan, E.V., Maheshwarudu, G., Arputharaj, M.R. and Gopalakrishnan, K.N., 1991. Successful Searanching Programme or Shrimps by CMFRI. *CMFRI Newsletter*, 52: 1-3.

Robert, G.S. and Sonujj Choule, 1983. Artificial Habitat Technology in the World - Today and Tomorrow. Paper presented at Japan - US Symposium on Artificial Habitat for fisheries Proceedings 1991, Tokyo, Japan, pp. 3-9.

Victor, A.C.C. and Velayudhan, T.S., 1996. Pearl oyster farming and pearl production. *Bull Cent. Mar. Fish. Res. Inst.*, 48: 56-63.

Venkataraman, G., Ammerhamsa, K.M.S. and Nammalwar, P., 1985. Fish culture in pens in the Gulf of Mannar, India. *Proc. Symp. Coastal Aquaculture*, 3: 951-954., Mar. Bio. Ass. India, 12-18 Jan., 1980, Cochin.

4

Application of Genetics to Aquaculture: Challenges, Strategies and Principles*

MERYL J. WILLIAMS

International Centre for Living Aquatic Resources Management (ICLARM)
Manila, Philippines

1. Introduction

I wish to draw your attention to some basic strategies and principles of aquaculture genetics, as we at ICLARM see them. We are of course guided by our colleagues from the world of plant and animal breeding. To set the stage for discussion, I wish to paint with a broad brush some challenges ahead of us.

We all are aware of the rapid changes in our world. The pace has been so overwhelming that the resources that support and sustain life on this planet are threatened. The threat comes mainly from unprecedented world population growth, super fast economic growth, and the ever increasing human demands which are fast exceeding the limits of earths natural resource systems. About 90 million people are being added on this planet, year after year. We have virtually crossed the thresholds of almost all sectors of food supply due to factors such as overfishing, overgrazing, soil erosion, deforestation, etc. We have to regain control of our destiny.

Capture fisheries, hitherto considered as one of the last frontiers for supply of affordable animal protein, is also severely threatened. Over one billion people in developing countries depend on fish as the primary source of animal protein. In Asia and the Pacific region, fish provides about 50 to 70% of animal protein and contributes substantially to the economics of the developing nations. Since about 1990, however, the gap between the demand for and supply of food fish has been rapidly widening due to stagnating production of capture fisheries resulting from overfishing and destructive fishing practices and

* *Prepared by Ambekar Ekanath, Genetic Enhancement and Breeding Program (GEBP), ICLARM, Manila, Philippines.*

AQUACULTURE AND THE ENVIRONMENT
ISBN 81-85340-17-X

increasing demand due to population growth and per capita income. To maintain consumption at about its current level (13.0 kg/caput/year in live-weight equivalent), the Food and Agriculture Organization of the United Nations predicts that the world will require food fish supplies of about 91 million tonnes. The contribution to food fish from marine and freshwater fisheries is likely to oscillate around 60 million tonnes per year. Consequently, the balance of 31 million tonnes in the supply of food fish required by the year 2010 would have to come from aquaculture. This implies a doubling of the estimated 1993 aquaculture production of nearly 16 million tonnes. We are confronted with the challenge of doubling of aquaculture production in about 10 years. Most of the production will continue to come from developing Asian countries and from freshwater fish species, in particular, Asian carps and tilapias, which together form the mainstay of many small-scale aquaculture enterprises in the tropical developing world.

2. Genetic Improvement

Genetic improvement is one of the promising approaches to increasing aquaculture yields per unit area and time, as demonstrated in agriculture and livestock. Application of genetics in aquaculture, however, has just begun. Many of the most widely farmed fish species were not even bred in captivity until the 1960s. Consequently, productivity is low and the stocks used in aquaculture are generally similar to wild undomesticated stocks and in some situations there is strong evidence of genetic deterioration. This is analogous to the situation in the development of agriculture long before crop plants and domestic mammals and birds reached their present level of production efficiency.

Strategic research for genetic improvement of aquatic organisms in general must consider a long-term view of the global needs for documentation/conservation, evaluation, and utilization of genetic resources. It should consider not only the technical aspects of breed improvement (such as genotype x environment interactions) but also the perspectives of users - farmers and consumers. It should serve the existing and the emergent aquaculture enterprises. Genetic improvement and development of improved breeds, however, is only the half the story. The other crucial aspect is their dissemination to reach the targeted beneficiaries effectively, including monitoring of the impact and adoption of improved breeds. Management of and access to germplasm are also becoming increasingly important issues, under the new Convention on Biological Diversity, which went into force about three years ago.

It should also be recognized that tropical aquaculture at present typically involves simple, low external-input systems, operated by small-scale farmers. These systems are far from reaching their optimal efficiency. The general economic and infrastructure development are also very incomplete. However, aquaculture represents a new dimension in farming systems and a potential new venture for millions of small-scale farmers whether in the form of fish farms per se or new components integrated with other agricultural enterprises. Therefore, genetic improvement strategies destined to benefit the majority of peoples in the aquaculture industry should, to the extent possible, involve relatively minor or gradual structural changes. The products of genetic research must help to consolidate the pivotal role of small-scale farmers in food production and food security.

It is with this basic guiding principles that ICLARM, in co-operation with the Philippine national institutions (Bureau of Fisheries and Aquatic Resources and the Central Luzon State University) and the Norwegian Institute of Aquaculture (AKVAFORSK), initiated the global project on the "Genetic Improvement of Farmed Tilapias" (the GIFT Project), funded by the United Nations Development Programme and the Asian Development Bank. This work has already led to the establishment of: (a) National Tilapia Breeding

Programs in the Philippines, Vietnam and Bangladesh; and (b) the International Network on Genetics in Aquaculture (INGA) participated in by 14 Asian and African countries.

3. Breeding Strategies

The relatively simple breeding strategies that ICLARM and its research partners have pioneered for the developing world, using Nile tilapia as a test species, are extremely effective contributors to increasing the productivity and production efficiency of aquaculture. Conventional selection programs are well regarded in public opinion. In one form or the other, they account for most of the improvements that have been made in domesticated plants and animals. They serve a very useful public service function relatively free of profit motives, intellectual property rights, and the structural changes for implementing such programs are relatively minor. Selection, however, is not an exclusive approach. Emergent biotechnological approaches can be woven into such breeding programs, after assessing their impact on biodiversity, socioeconomics and the environment.

4. Case Studies

Some approaches to apply the basic principles of quantitative genetics to aquaculture are focused below.

The first of these is an attempt to demonstrate, using Indian carp culture as an example, how relatively minor changes in routine broodstock management practices can result in maximising the genetic potential of aquaculture stocks.

The second case study on Nile tilapia, through the GIFT Project, demonstrates the enormous gains in production efficiency that are possible from a systematic selection program. The GIFT research on Nile tilapia is one major example of multidisciplinary and participatory research initiative in the Region. It has successfully integrated a number of activities along the continuum from the documentation of tilapia genetic resources through to their systematic evaluation and utilization in national breeding programs. It has explicitly considered ex-ante the potential benefits to a spectrum of aquaculture enterprises, ranging from extensive small-scale to semi-intensive medium-scale farms.

4.1. Simple broodstock management practices to control indirect selection and inbreeding in aquaculture of Indian major carps

This case study on Indian major carps is based on a series of studies (spanning about 10 years) carried out by ICLARM Scientist Ambekar Eknath along with his research supervisor Prof. Roger Doyle of the Dalhousie University (Eknath and Doyle, 1985a, 1985b, 1990; Eknath, 1991). One of the major conclusions of this study can be paraphrased as follows:

"Far from being sources of improved fish seed to fish farmers, some Indian carp hatcheries may actually be doing the reverse – inadvertently causing deleterious inbreeding and negative selection (during routine broodstock management and fish seed production) and, thereby, producing slower growing fish ... every generation and every cycle of fish seed production"

Overall, these studies have been considered by scientist-peers around the world as "pioneering and bench-mark" studies in tropical fish breeding and genetics. It has involved a biological system, the genetics of which were virtually unknown. There was also was very little background information to initiate the research with.

It was initiated to explore the widespread concerns among Indian fish farmers and government hatchery managers that: (a) growth performance of Indian carps in aquaculture systems were declining year after year; (b) culture carp stocks may be severely inbred; (c) there were increased incidence of morphological deformities among some carp species. Through deductive reasoning (*i.e.* after accounting for various other factors such as pond fertilization procedures, water quality, ambient temperature, *etc.*), the hatchery managers had concluded that the problems they encountered were mostly genetic in nature.

The study began by laying down a conceptual research framework to analyse the various "selection pressures" that cultured fish stocks have to contend with in closed aquaculture systems and then has proceeded to obtain quantitative estimates of selection pressures and rates of inbreeding. It also recommends some practical solutions to avoid such indirect selection and inbreeding.

Research framework

Aquaculture systems can be broadly classified into two categories: "Open" and "Closed" - depending on the way in which young fish are obtained for rearing and on the scope for possible genetic changes.

In the open system, the production cycle begins by collecting young fish from nature and rearing them to harvestable size under controlled conditions. Many aquaculture enterprises depend on natural sources for the supply of fish seed. Notable examples are milkfish, mullets, and shellfish farming. Since the production invariably ends, there is very little scope for cumulative genetic changes.

In the closed system of aquaculture, individuals raised within the system contribute progeny to the next round of production. This will then accumulate genetic effects from generation to generation. Genetic changes in closed populations can result not only from conscious efforts to directly improve the stocks but also from "indirect" selection brought about by inadvertent aquaculture management practices plus natural selection within the aquaculture realm.

In the case of aquaculture of Indian carps, since the advent of the hypophysation technique of induced spawning in the mid-1950s, carp hatcheries have been virtually closed to genetic exchange with the wild stocks. Hatcheries routinely raise their own stock of breeders and usually do not receive back mature individuals from grow-out areas. Each carp hatchery, therefore, can be regarded as an isolated, self-sustaining, genetically closed unit. Whether or not conscious artificial selection for genetic improvement is practised, there will always be indirect selection pressures exerted by farm management practices such as choice of founding stock, the number of breeders maintained in the hatcheries, the type of mating system followed during artificial propagation and seed production, the method of replenishing the broodstock, stocking density, feeding regime, etc. Such accumulation of genetic changes from generation to generation will eventually lead to permanent changes in the cultured stocks. The impact of such indirect selection can be of same magnitude as direct, conscious selection, and can either augment or diminish the effectiveness of organized selection programs. Therefore, a careful analysis and designing of management practices to control these selection forces is necessary in order to maximise the genetic potential of the cultured stock.

Estimation of indirect selection

An essential pre-requisite for selection analysis is data on comparative performance of individuals in a population. Specifically, "longitudinal" data on traits such as growth rates, age at first maturity, and general growth performance throughout the life of an individual are necessary. Such data were unavailable from Indian carp hatcheries. Eknath and Doyle (1985a) estimated these growth and reproduction parameters by statistical manipulation of information from important fish scale features, namely, number and radial measurements of growth checks, circuli counts, and circulus spacing. The approach was to develop a linear structural equation model by specifying a priori the interrelationships between the "observed" scale features and the unobserved life-history variables to be estimated. The distribution of variables were assumed to be multivariate normal and the solution to the structural model was obtained by confirmatory factor analysis.

The quantitative estimates of various life-history traits were then used to determine the mean superiority of individuals (for a given trait) selected relative to the mean population value. In genetic parlance, this is called intensity of selection. In the fish hatcheries surveyed in Karnataka State, the results indicated that the broodstock selection was size selective, exerting strong negative selection on pre-spawning growth performance and strong positive selection on age at first spawning. In other words, there was a tendency in these hatcheries to breed inadvertently slower growing and later maturing individuals. The rate of response under this "negative" selection regimen could not be predicted because heritabilities and genetic correlations between various life-history traits are not known. The overlapping generations and multiple-age structure of the carp populations is another factor to be considered in determining the response to selection. Nevertheless, one of the easiest ways of avoiding such negative selection is to select broodstock when they are young and when only fast growing individuals have matured. A hatchery manager may also consider marking of individuals of different year classes. This way, relatively larger individuals of a given yearclass can be chosen for seed production and broodstock replenishment.

Estimation of rates of inbreeding

Framework for analysis: Inbreeding can be broadly defined as the mating together of individuals that are related to each other by common ancestry. The degree of relationship between mating pairs is measured as the coefficient of inbreeding (F). Inbreeding is a cumulative phenomenon. The rate of accumulation of inbreeding per generation is denoted by F. The key parameter for estimating rate of inbreeding is the effective population size (N_e). F is inversely related to N_e.

In finite genetically closed hatchery populations, inbreeding can occur when individuals for replenishment of broodstock come from within the same hatchery. The parameter, N_e is determined not by the total number of breeders used for fish seed production every year but by the number of individuals that eventually contribute progeny for the replenishment of the broodstock. Specifically, it is the family size and replacement success which determine N_e. Family size refers to the number of progeny of a parent that eventually become breeding individuals in the next generation. N_e will also be determined by the number of males and females contributing progeny to the broodstock pool.

In order to estimate inbreeding the broodstock management practices should first be mapped and understood. Since data on pedigree of individuals and/or direct census data for estimation of inbreeding using conventional techniques were not available, Eknath and Doyle (1990) estimated N_e and the rate of inbreeding as a function of the number of individuals entering the broodstock population each year and the variance of their reproductive success.

Results from a survey of carp hatcheries throughout Karnataka State indicated that the effective population size N_e ranged from as low as 3 to a maximum of only 30, and the rate of inbreeding ranged from 2% to 17% – an evidence that there was indeed rapid inbreeding of carp stocks in hatcheries.

Significance of the study

For the first time, Eknath and Doyle were able to explore and provide some practical solutions to the widespread declining growth performance of hatchery-reared Indian carps. Overall, the research has led to: (a) the understanding of the impact of "indirect" selection exerted during routine hatchery management practices; (b) approaches to estimate (and the first ever estimates) the magnitude of "indirect" selection and the rates of inbreeding; (c) practical recommendations to avoid negative selection and inbreeding. The study also demonstrates that, even in the absence of an organized genetic improvement program, relatively minor changes in routine broodstock management practices in Indian carp hatcheries can bring about rapid genetic gains in growth performance of aquaculture stocks. The key to this, however, is to maintain proper records of various hatchery management practices and performance of stocks at various stages of the production cycle. Genetic gains in growth performance in the range of 10 - 15% per generation are possible. Lastly, without this study, an extremely cost-effective and simple approach to genetic improvement of carps would almost certainly have been neglected.

This study has also laid the foundation for several major aquaculture genetics research initiatives in India: (a) the India-Norway collaborative research project on the 'Selective Breeding of Rohu' at the Central Institute of Freshwater Aquaculture (CIFA) sponsored by the Indian Council of Agricultural Research and the NORAD; (b) The India-UK project on the "Genetic Improvement of Catla" at the University of Agricultural Sciences, Bangalore.

Under the auspices of INGA, ICLARM in partnership with Bangladesh, Peoples Republic of China, India, Indonesia, Thailand and Vietnam, will soon initiate a collaborative research and training project on the Genetic Improvement of Carps in Asia. This project will be funded partially by the Asian Development Bank.

This Project seeks to build on early research on genetic improvement of carps for aquaculture. The planned major activities during the first phase of the Project (first quarter of 1997 to Dec. 1999) will include: (a) systematic documentation of carp genetic resources for aquaculture; (b) prioritization of species, farming systems, and breeding goals; (c) designing of research activities based on identified priorities; and (d) start-up of research activities leading to the development of genetically improved carp strains.

Work will begin after an extensive, objective and pragmatic research prioritization exercise. ICLARM and its partners will be (a) assessing how and to what extent existing carp species/strains are valued by different groups; (b) estimating future demand by income groups: (c) analyzing present and future importance of various carp-based farming systems; (d) assessing the relative economic importance of various traits. The analysis will be based on field surveys and secondary information. Based on the results of the priorities exercise, location-specific genetic experiments will be initiated.

Systematic documentation of carp genetic resources will involve collation of all available information, including indigenous knowledge in the participating member-countries. Workshops will be held prior to and after this exercise and the outcome will be a book on "Carp genetic resources for aquaculture in Asia." Training will be organized by ICLARM and its partners in the assessment of genetic resources, quantitative genetics, methods for research prioritisation and applied carp breeding techniques.

4.2. Genetic improvement of Nile tilapia *(Oreochromis niloticus)*

Background

Tilapia farming worldwide is now in a dynamic state of expansion to satisfy both the domestic and international markets. FAO statistics report tilapia culture in at least 75 countries. Although several tilapia species are cultured, the most widely preferred (in over 40 countries) is the Nile tilapia Oreochromis niloticus, which contributes about 55% to the global production of about 450,000 t (Pullin *et al.* 1994).

Unlike the farming of many species of indigenous fish in the tropics and the subtropics, the tilapias represent a special scenario. The natural tilapia genetic resources are restricted to Africa and the Levant, whereas the main aquaculture industries are at present in Asia, where they contribute about 10% of the total finfish production from aquaculture. The global outlook for tilapia farming has been dealt with extensively by Pullin *et al.* (1994). Pullin (in press) has described in detail the perceived constraints to future expansion of tilapia culture. These include negative attitudes and policies, inadequate research support, poor breeds, poor non-sustainable farming systems, and possible adverse environmental impacts.

Tilapias also have the rare distinction of being the subject of more research and debate than perhaps any other tropical farmed fish (Pullin *et. al.* 1994). In addition to the vast information compiled from various field and laboratory sources, three international symposia on tilapias in aquaculture have been held. The knowledge base, however, still lacks an interdisciplinary approach to match development efforts and the needs and circumstances of producers and consumers (Pullin and Maclean, 1992).

The focus of this part of the presentation is on the results of a multidisciplinary research initiative being carried out by ICLARM and its research partners – from documentation of tilapia genetic resources, their systematic characterization, evaluation, and utilization in applied national fish breeding programs, to monitoring of the adoption of genetically improved tilapia breeds with due regard to their impact on equity, environment, and biodiversity.

The need for genetic improvement

As described earlier, natural tilapia genetic resources are restricted to Africa whereas the main aquaculture industries are at present in Asia. The history of introductions of tilapias (described above) suggests that most farmed tilapias derive from very small founder stocks (as reviewed earlier by Pullin and Capili, 1988; Eknath, 1995). With the notable exceptions of Israel and to a certain extent, of Taiwan, genetic improvement research destined to benefit the existing and the emergent tilapia industry has scarcely begun. The cost of lost opportunities has been considerable. The stocks in current use by Asian farmers are close to wild undomesticated stocks or perhaps worse (Eknath *et al*, 1993).

Application of genetics to tilapia farming, on the other hand, can be a complex activity for several reasons: (a) diversity of farming systems; (b) diversity of needs and opportunities in tilapia-growing countries; (c) diversity of markets; and (d) the general lack of infrastructure development to successfully disseminate the results of genetic improvement programs to benefit producers and consumers.

The basic strategy and principles

Before embarking on a research effort in genetics, it should be recognized that the tilapia industry at present is evolving. Aquaculture in general and tilapia culture in particular, represents a new dimension in fish farming not only to the existing farmers but also potentially to many new entrants to aquaculture. At present, as seen in the poultry industry, the 'backyard' type tilapia farming coexists with relatively sophisticated medium- and large-scale corporate farms. Therefore, equity and socio-economic impacts of research are important considerations. Also, genetic improvement strategies destined to benefit the aquaculture industry should, to the extent possible, presume relatively minor or gradual structural changes. The lessons learned from agriculture and livestock research cannot be ignored. While the products of genetic research should assist in enhancing the competitiveness of the private sector, it should, at the same time, consolidate the pivotal role of small-scale farmers in food production and food security.

With these guiding principles, ICLARM initiated a major strategic research and training initiative in fish breeding genetics through the UNDP/ADB-funded project known as the "Genetic Improvement of Farmed Tilapia" (GIFT). The primary objective was to develop effective ways of producing improved breeds of Nile tilapia for low external input aquaculture systems, and to provide improved breeds to national and regional testing programs in cooperation with farmers.

4.3. The GIFT project

The Project was established in 1988 through collaboration among the Philippine national institutions (Bureau of Fisheries and Aquatic Resources, the Central Luzon State University and the University of the Philippines), the Norwegian Institute of Aquaculture Research (AKVAFORSK), and ICLARM, and funded by the UNDP and ADB.

The process

At the very outset, the GIFT team considered the relative economic importance of each of the diverse tilapia farming systems. A grow-out period of 90 days was chosen as a representative production cycle. Research methods for evaluation of culture performance in these diverse test environments were then refined.

Based on a 1987 Workshop in Bangkok recommendations and identification of sources of pure tilapia stocks, the GIFT team made the first ever collections in 1988 and direct transfer of Nile tilapia from Africa to tropical Southeast Asia. Breeders (150-160) or fingerlings (200-800) were collected in Egypt, Ghana, Kenya and Senegal, in collaboration with, among many, the University of Hamburg, Germany; the Musee Royal de l' Afrique Centrale, Tervuren, Belgium; the Institute of Aquatic Biology, Ghana; the Suez Canal University and the Central Laboratory for Aquaculture Research, Egypt; and the Baobab Farms, Mombasa, Kenya. The fish were held in quarantine at NFFTRC/BFAR. The team worked with the BFAR Fish Health Unit to develop quarantine protocols: a model for use elsewhere. Experimental stocks of four Philippine commercial Nile tilapia strains were also gathered, giving a total of eight strains for study. All eight strains were described using biochemical and morphometric techniques and held in a newly constructed Tilapia Germplasm Reference Collection Center at the NFFTRC/BFAR. Spermatozoa from tilapia founder stocks and selected breeders are also cryopreserved, as part of a small tilapia genebank, for further research.

The Project's first experiment was to investigate the magnitude of genotype x environment interactions (GE). A total of 11,400 individually tagged fingerlings from all eight founder strains were distributed to 11 test environments and communally reared for about 90 days. The GE was very low, indicating no need to develop environment-specific strains for each of the different farming systems used in the test. Some of the African strains grew much faster than the Asian farmed strains.

This GE experiment was followed by a complete 8 x 8 diallel crossing experiment, producing all 64 possible hybrid crosses among the strains in order to estimate the magnitude of heterosis or 'hybrid vigor'. The estimated gain in growth and survival by crossbreeding was too low to be of significance in an applied breeding program. A simple pure breeding strategy was then started by selecting best growing individuals from the 25 best performing purebred and crossbred groups (out of the 64 evaluated) to build a genetically mixed base population (synthetic breed). This synthetic breed served as the base for further generations of selection and purebreeding.

Selection means breeding from the 'best' individuals. In one form or another, it accounts for most of the improvements that have been made in domesticated plants and animals. There has been no equivalent effort for fish. The GIFT team adopted a combined family and within family selection strategy. The test fish were ranked based on 'breeding value' - the additive genetic value of an individual - estimated by evaluating the performance of the individual itself and its full- and half-sibs. After only one generation of selection in the synthetic breed, the selected fish grew 26% faster in on-station trials than the previous generation and 75% faster than the most commonly farmed strain in the Philippines. The team has been evaluating in every successive generation, about 20,000 individually tagged fingerlings from 120-200 selected full-sib families (within 100 half-sib families) in a variety of test environments.

The GIFT strain is now in its sixth generation of combined family selection. The average genetic gain per generation across five generations of selection carried out so far has been about 12-17%. The potential for developing late-maturing tilapias and inclusion of this important trait in the on-going selection (for growth performance) program are being investigated.

Some early impacts

In 1993, the Philippine President, Fidel V. Ramos, launched the national distribution of the GIFT Breed. The Philippines has since initiated a National Tilapia Breeding Program. In preparation for the development of national tilapia breeding programs elsewhere in Asia, the social, economic and environmental impact of new tilapia breeds are being investigated in a range of aquaculture systems in Bangladesh, China, Indonesia, Thailand and Vietnam.

The early achievements of the GIFT Project has already led to the establishment of an International Network on Genetics in Aquaculture (Seshu *et al.* 1994). Thirteen countries are collaborating in research and exchange of genetic materials, initially tilapias and carps: Bangladesh, China, Cote d'Ivoire, Egypt, Fiji, Ghana, India, Indonesia, Malawi, Malaysia, the Philippines, Thailand and Vietnam. ICLARM is the member-coordinator.

Nature of GIFT technology

The GIFT Project has demonstrated clearly the enormous gains in economic performance of farmed tilapia that are possible from a systematic selection program. Without it, an extremely cost-effective and simple route to genetic improvement would almost certainly have been further neglected in favor of more costly and complex genetic management and biotechnological approaches. As pointed out earlier, selective breeding is not an exclusive approach. Emergent technologies such as ploidy manipulation, transgenics, etc., can be woven into such breeding schemes, after assessing their environmental and social impacts.

The comparative performance of GIFT and existing tilapia (mostly 'Israel' strain) strains was evaluated in 8 provinces of the Philippines, representing different agroecological environments, during 1992 to 1994. Results reveal that the GIFT strain has a significant and positive impact on both average weight and survival rate. The GIFT strain had 37% higher growth rate and about 23% higher survival rate.

To investigate the performance of the GIFT strain under the diverse environments of tilapia producing countries of Asia, the GIFT fish are being tested in 5 countries outside the Philippines: Bangladesh, China, Indonesia, Thailand, and Vietnam. In Bangladesh, where Nile tilapia has a short history with very limited broodstock management, the GIFT strain appears to be 50% superior, in terms of growth, to local strain. In China, Indonesia, Thailand and Vietnam, where there are longer histories of tilapia farming, greater climatic variation, and therefore the possibility of both natural and artificial selection of local strains to their environments, the GIFT strain appears to be about 10-15% superior to local strains in terms of growth. The on-station data did not show any definite pattern in terms of survival.

We fitted a stochastic frontier model of average weight at harvest based on the on-station experimental data from Bangladesh, China, Thailand and Vietnam using the maximum likelihood estimation technique. The estimated frontier model shows the maximum body weight that can be obtained from a specific level of inputs. The yield potential of the GIFT strain is about 11% higher than that of the best existing strain. It is worthwhile to note here that the GIFT strain is performing well in all the location and the existing strains are location-specific; a particular local strain may be better in one location but not in another.

The use of sex-reversal technology with the GIFT fish can raise the yield potential of Nile tilapia further. Results of experiments conducted at the Asian Institute of Technology (AIT), Thailand indicate that the net yield of sex-reversed GIFT fish was 28% higher than the yield of sex reversed Chitlada strain and 24% higher yield was observed for non sex-reversed GIFT fish over Chitlada strain. The net yield of sex-reversed GIFT fish was about 5% higher than that of non sex-reversed GIFT fish.

Product market effect of GIFT technology

The gain from research in any commodity and its distribution among various strata of society depends on, among other factors, price elasticities of demand for and supply of the commodities, proportion of output consumed at home, and the level of international trade.

As the GIFT technology will enable the farmers to produce more using the same level of inputs, the cost per kilogram of fish produced should decline. In countries like Taiwan, where the international trade affects the tilapia price, the adoption of yield increasing GIFT technology may not cause major price reduction and most of the benefit due to the adoption of technology will accrue to producers in direct proportion to their sales.

In the Philippines and Thailand, where about 80-90% of tilapia production are marketed, consumers will generally benefit from technological progress (the GIFT technology). As tilapia is consumed mainly by poor people because of its relatively low price and as the price elasticity of demand for fish is higher for poorer people than for the rich, yield increases by using GIFT fish would benefit mostly these poor consumers.

In countries like Bangladesh, where tilapia fish farmers consume about 70% of their produce, the major portion of economic gain that is due to the adoption of GIFT technology will be internalized by producers, especially the small subsistence ones. In subsistence farming, the reduction in market price due to higher production has relatively little influence on producers' income.

References

Eknath, A.E. and Doyle, R.W., 1985. Indirect selection for growth and life - history traits in Indian Carp Aquaculture 1. Effects of broodstock management. *Aquaculture* 49(1):73-84.

Eknath, A.E. and Doyle, R.W., 1985. Maximum likelihood estimation of 'unobservable' growth and development rates using scale data application to carp aquaculture in India. *Aquaculture* 49(1):55-71.

Eknath, A.E., and Doyle, R.W., 1990. Effective population size and rate of inbreeding in aquaculture of Indian major carps. Aquaculture 85(14): 293-305.

Eknath, A.E., 1991. Simple broodstock management to control indirect selection and inbreeding: Indian carp example. *NAGA:ICLARM Q.* 14(2):13-14.

Pullin, R.S.V., Bimbao, M.A.P. and Bimbao, G.B., 1994. World outlook for tilapia farming. Paper presented at the First International Symposium on Aquaculture, 9-11, June 1994, VeraCruz, Mexico.

Eknath, A.E., Tayamen, M.M., Palada de Vera, M.S., Danting, J.C., Reyes, R.A., Dionisio, E.E., Capili, J.B., Bolivar, H.L., Abella,

8179

T.A., Circa, A.V., Bentsen, H.B., Gjerde, B., Gjedrem, T. and Pullin, R.S.V., 1993. Genetic improvement of farmed tilapias: The growth performance of eight strains of *Oreochromis niloticus* tested in different farm environments. *Aquaculture* 111 (1/4):171-188.

Pullin, R.S.V. and Maclean, J.L., 1992. Analysis of research for the development of tilapia farming an interdisciplinary approach is lacking. *Neth. J. Zool.* 42(2/3):512-522.

Pullin, R.S.V. and Capilli, J.B., 1988. Genetic improvement of tilapias: problems and prospectus. *ICLARM Conf. Proc.* (15):259-266.

Eknath, A.E., 1995. The Nile tilapia, p. 176-194. In: Thorpe, J.E., G.A.E. Gali, J.E. Lannan and C.E. Nash. (eds.) Conservation of Fish and Shellfish Resources: Managing Diversity, Chapter 8. Academic Press, London.

Seshu, D.V., Eknath, A.E. and Pullin, R.S.V., 1994. International Network on Genetics in Aquaculture. International Centre for Living Aquatic Resources Management, Makati City.